Search for Higgs bosons at CMS in final states containing a tau

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On behalf of the CMS collaboration

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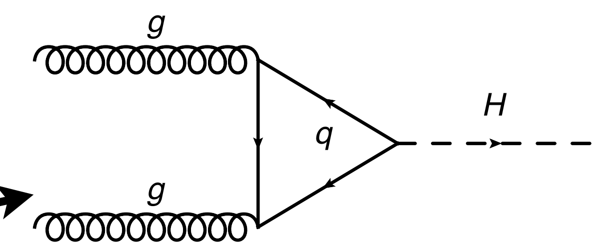
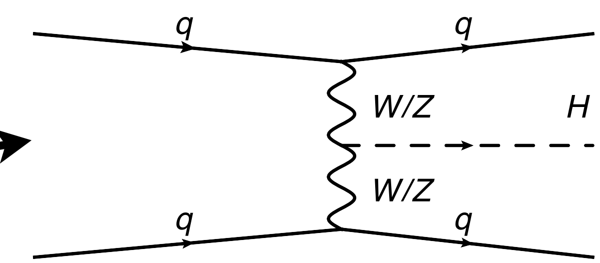
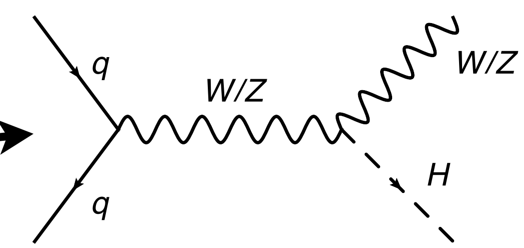
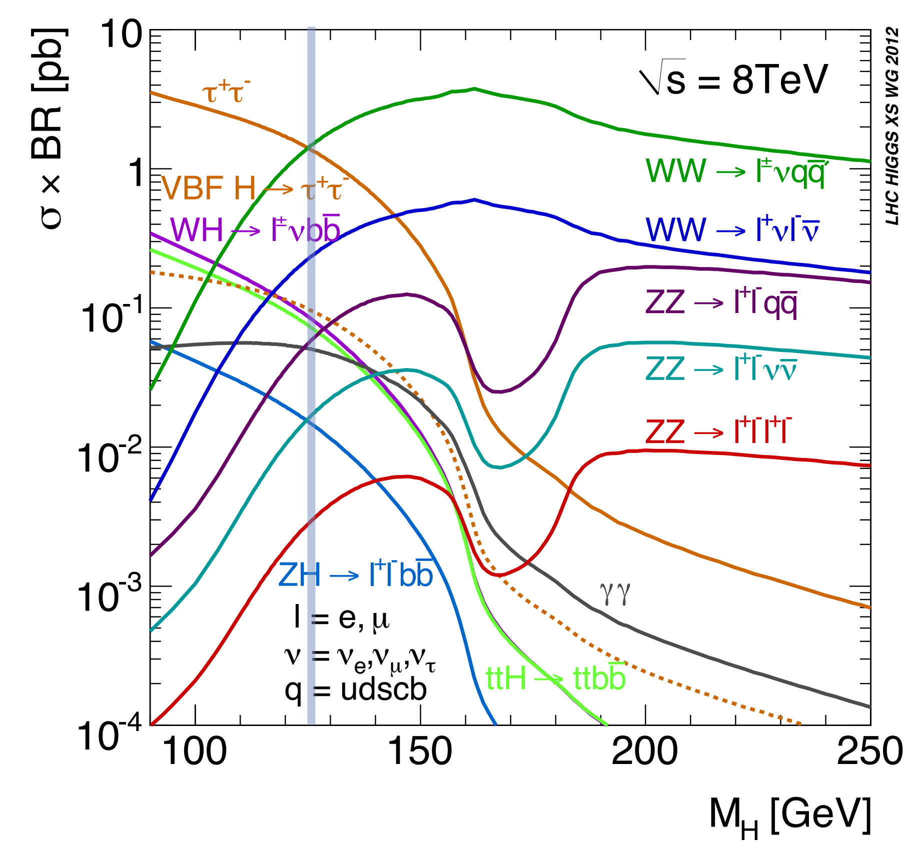
SM Higgs @ LHC

- Mainly comes in three flavors:
  - gluon fusion
  - **V**ector **B**oson **F**usion
  - Associated production with a vector boson
- Taus offer a great environment to search the Higgs boson due to the high σ×BR at low masses



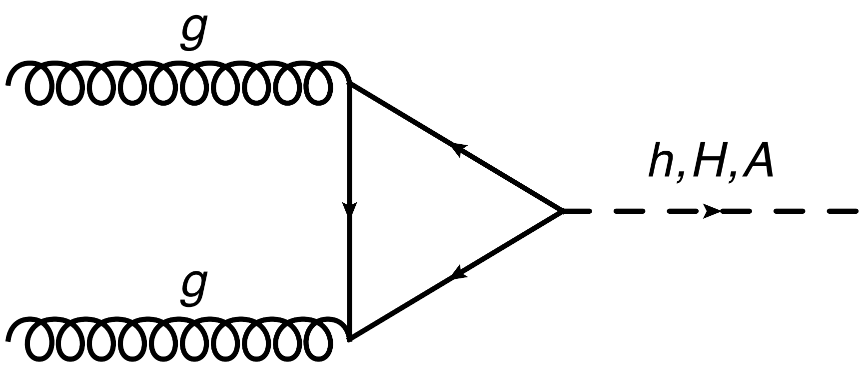


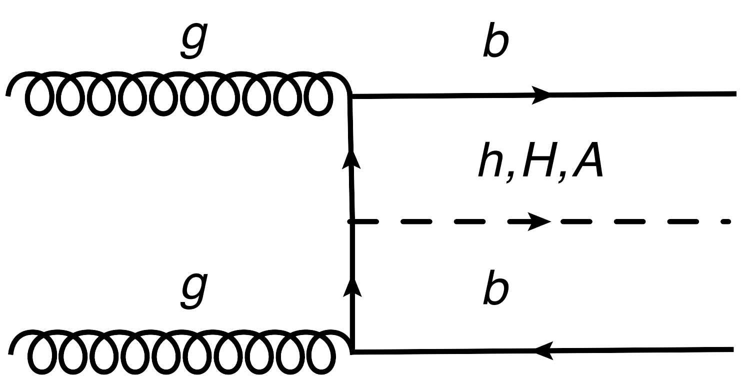




MSSM Higgs @ LHC

- MSSM extension:
  - Five physical bosons: h, H, A, $H^{\pm}$
  - At tree level masses and σ×BR controlled by two parameters: m_A and tanβ.
- Dominant decays into taus and b-quarks
- Enhanced production in association with b-quarks





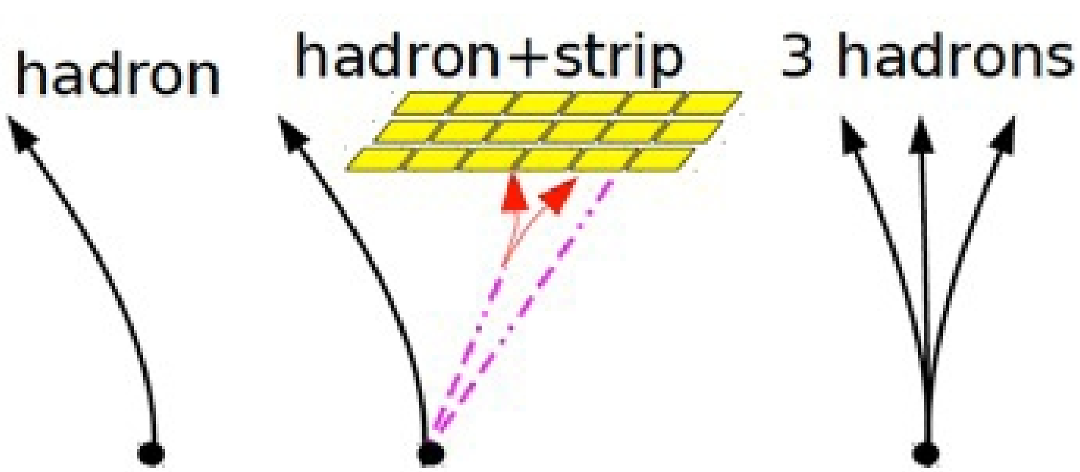
$H \to \tau\tau$ searches @ CMS

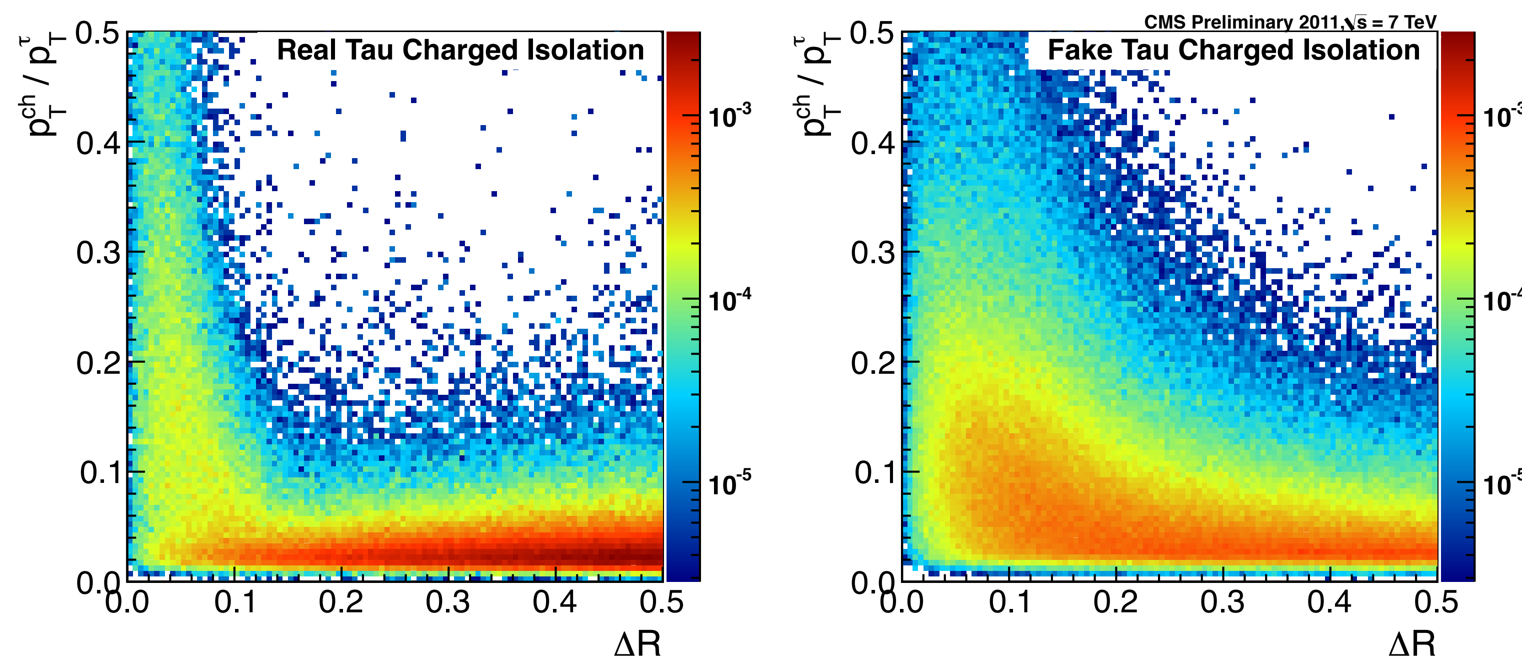
- SM Higgs boson searches include:
  - Five channels for direct production ($e\tau_h$, $\mu\tau_h$, $e\mu$, $\tau_h\tau_h$, $\mu\mu$)
  - Three macro-channels for associate VH production ($WH \to \ell\ell\tau_h$, $WH \to \ell\tau_h\tau_h$, $ZH \to 2\ell 2\tau$)
- Exploiting the full statistics collected by CMS so far (24.3/fb at $\sqrt{s}$ = 7-8TeV)
- MSSM searches include only ($\ell\tau_h$, $e\mu$, $\mu\mu$) and use only 17/fb ($\sqrt{s}$ = 7-8TeV)

Tools

Tau identification

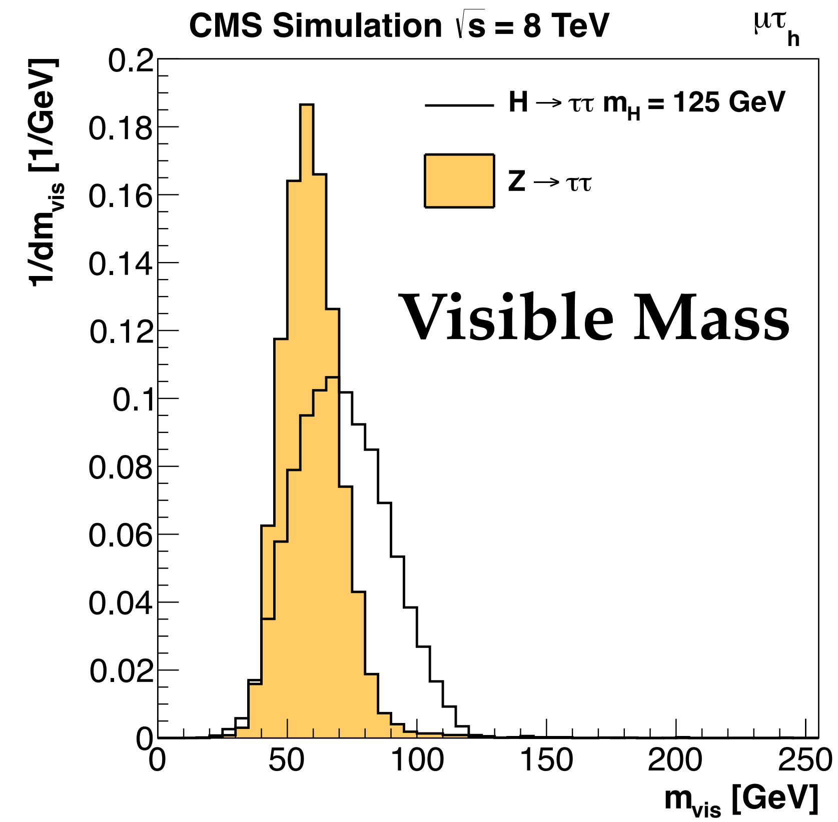
- Identification:
  - Based on **P**article **F**low objects
  - Reconstructs the decay modes starting from charged hadrons and ECAL strips
- Additional discriminators to reject light leptons
- Isolation:
  - BDT using the energy deposits in concentric rings around the tau
  - Pile-Up correction using FastJet rho

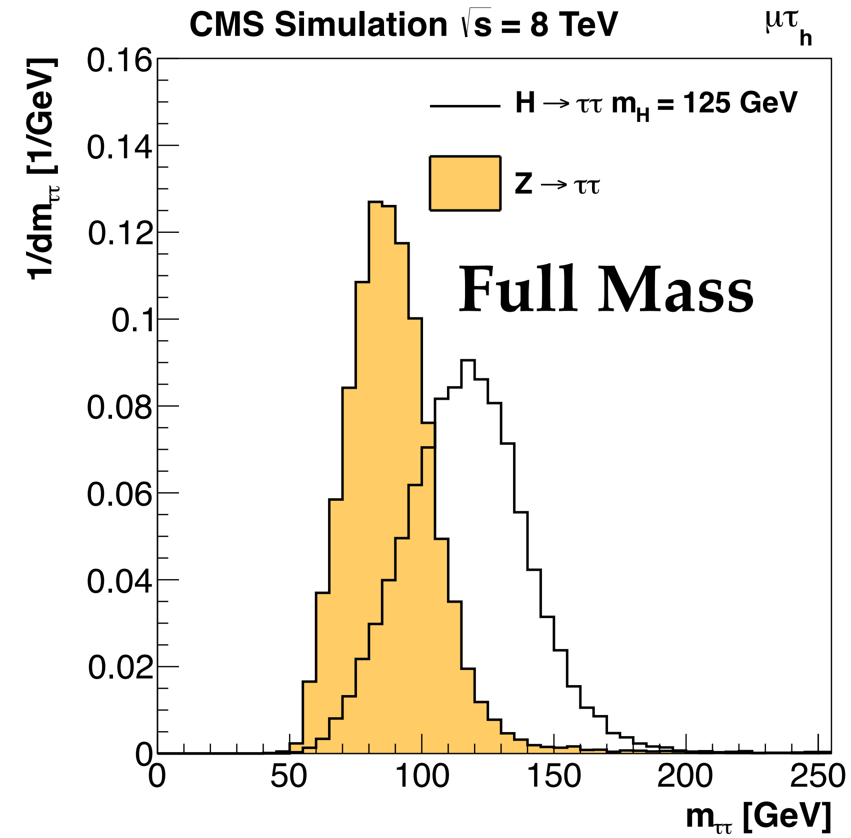




Mass reconstruction

- Tau decay involves one or two neutrinos smearing the visible invariant mass of the pair
- Use dynamical-likelihood method of full $m_{\tau\tau}$ hypothesis
- Computed event-by-event using the momenta of visible product, missing energy and its expected resolution
- Better resolution and Z/H separation





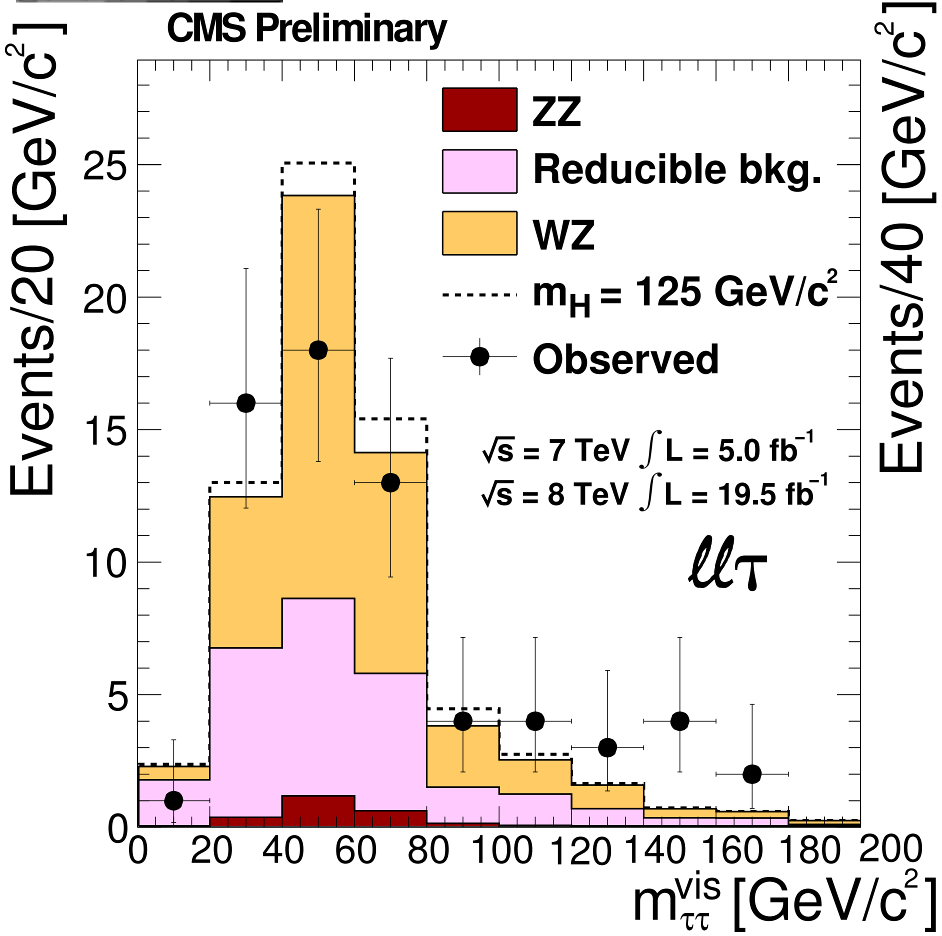
SM VH→ττ

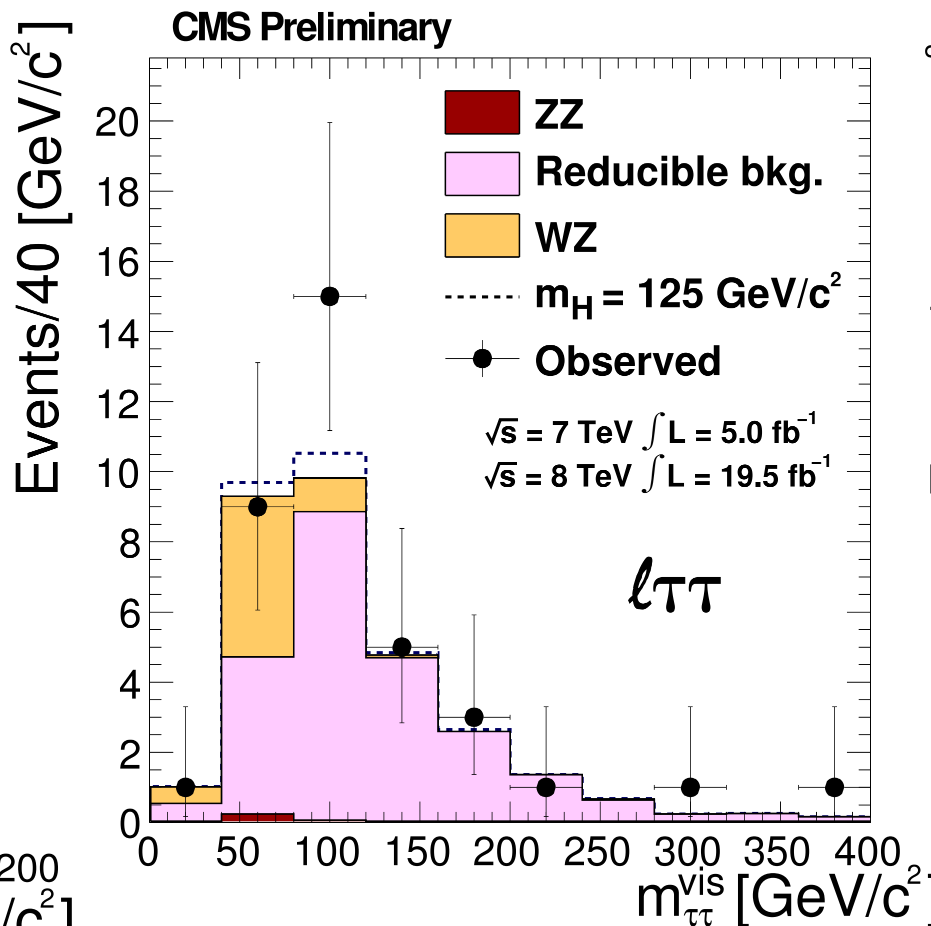
CMS PAS HIG-12-053

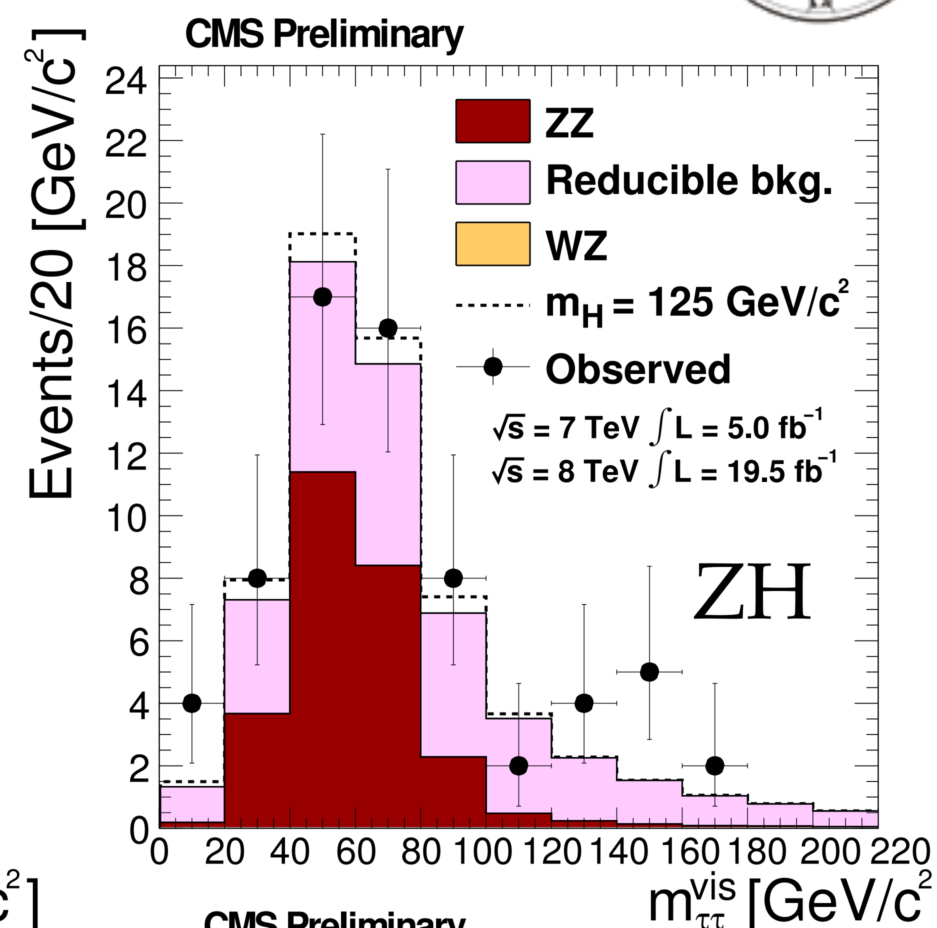
Analysis Higlights

- Background suppression:
  - WH $\ell\ell\tau$:
    - Light leptons are required to be **S**ame **S**ign to suppress **D**rell-**Y**an and ttbar
    - Cut on LT = $\sum p_T^{obj}$ to further reduce the backgrounds
  - WH $\ell\tau\tau$:
    - Tighter isolation and tau p_T requirements to suppress QCD and W+Jets
    - $M_T(\ell,MET)$ and MET cut to suppress DY
  - ZH:
    - Cut on LT to further reduce the backgrounds
- Veto any additional light lepton and b-tagged jets to reduce ttbar and ensure **orthogonality of the signal region w.r.t. other searches**
- Reducible background estimated with the **fake-rate method**
  - Fully data-driven
  - Uses sidebands where the objects fail the identification
- Irreducible background (diboson production) estimated with simulation

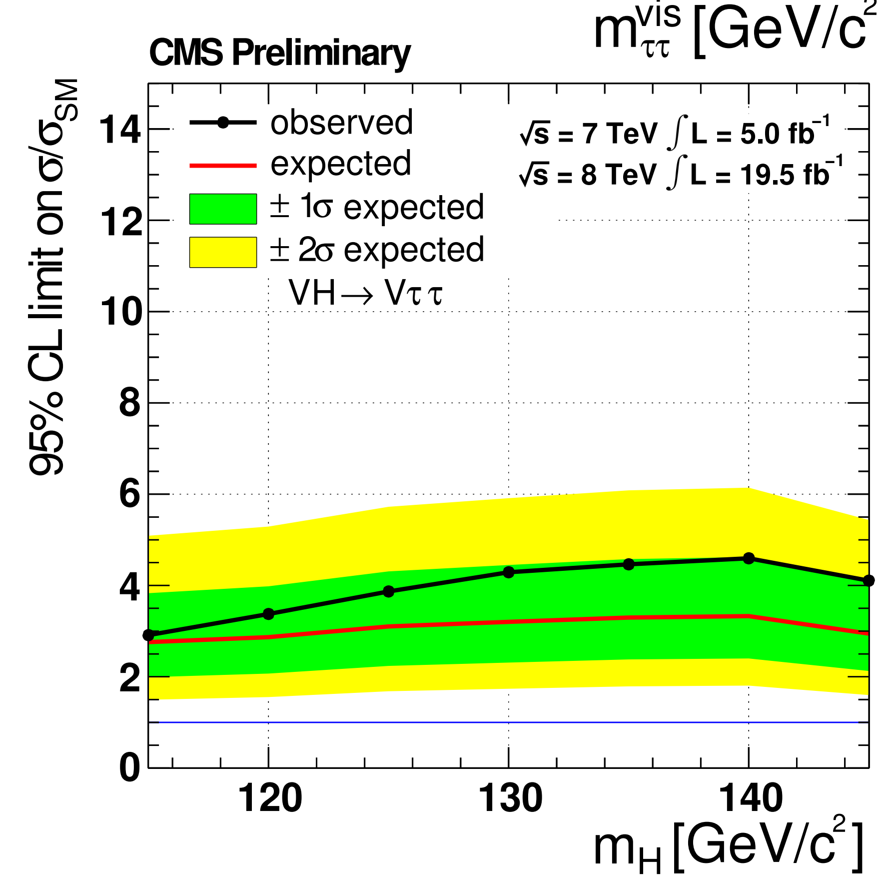
Results and limits







- Limit extracted from the **visible mass** of the tau pair
- Contribution of VH with H→WW is taken into account
    - negligible for $\ell\tau\tau$
    - drives high mass limit



SM H→ττ

CMS PAS HIG-13-004

Analysis strategy

- Select two well identified **O**pposite **S**ign lepton/hadronic taus
- Topological cut to suppress main background:
  - $M_T(\ell,\mathrm{MET}) < 20$ GeV to suppress W+Jets ($\ell\tau_h$)
  - $p_\zeta - 0.85\, p_\zeta^{vis} > -20$ GeV to suppress W+Jets ($e\mu$)
  - BDT selection to reject $Z\mu\mu$ events ($\mu\mu$)
  - $p_T^H > 140$ (110) GeV to reject QCD ($\tau_h\tau_h$)
- Simultaneous binned template fit of $m_{\tau\tau}$ in all the channels and categories

Event categories

\# of Jets

$\ell\tau_h$, $e\mu$, $\mu\mu$

τ_h/μ p_T

0 Jet	1 Jet	VBF
0 Jet, low p_T • Negligible signal contribution • Constrains backgrounds • **Singnal is not fitted**	**1 Jet, low p_T** • Boosted higgs • Better mass resolution	**VBF** • $\geq$ 2 Jets • $M_{jj} > 500$ GeV • $\Delta\eta_{jj} > 3.5$ • Central jet veto • VBF-enhanced region
0 Jet, high p_T • Negligible signal contribution • Constrains backgrounds • **Singnal is not fitted**	**1 Jet, high p_T** • Boosted higgs • Better mass resolution • $Z \rightarrow \tau\tau$ suppresses by p_T requirement	

$\tau_h\tau_h$

0 Jet	**1 Jet**	**VBF**
• Not available due to trigger constraints	• $p_T^H > 140$ GeV • QCD suppression	• $p_T^{\tau\tau} > 110$ GeV • $M_{jj} > 250$ GeV • $\Delta\eta_{jj} > 2.5$ • Central jet veto

Background estimation

Z→ττ

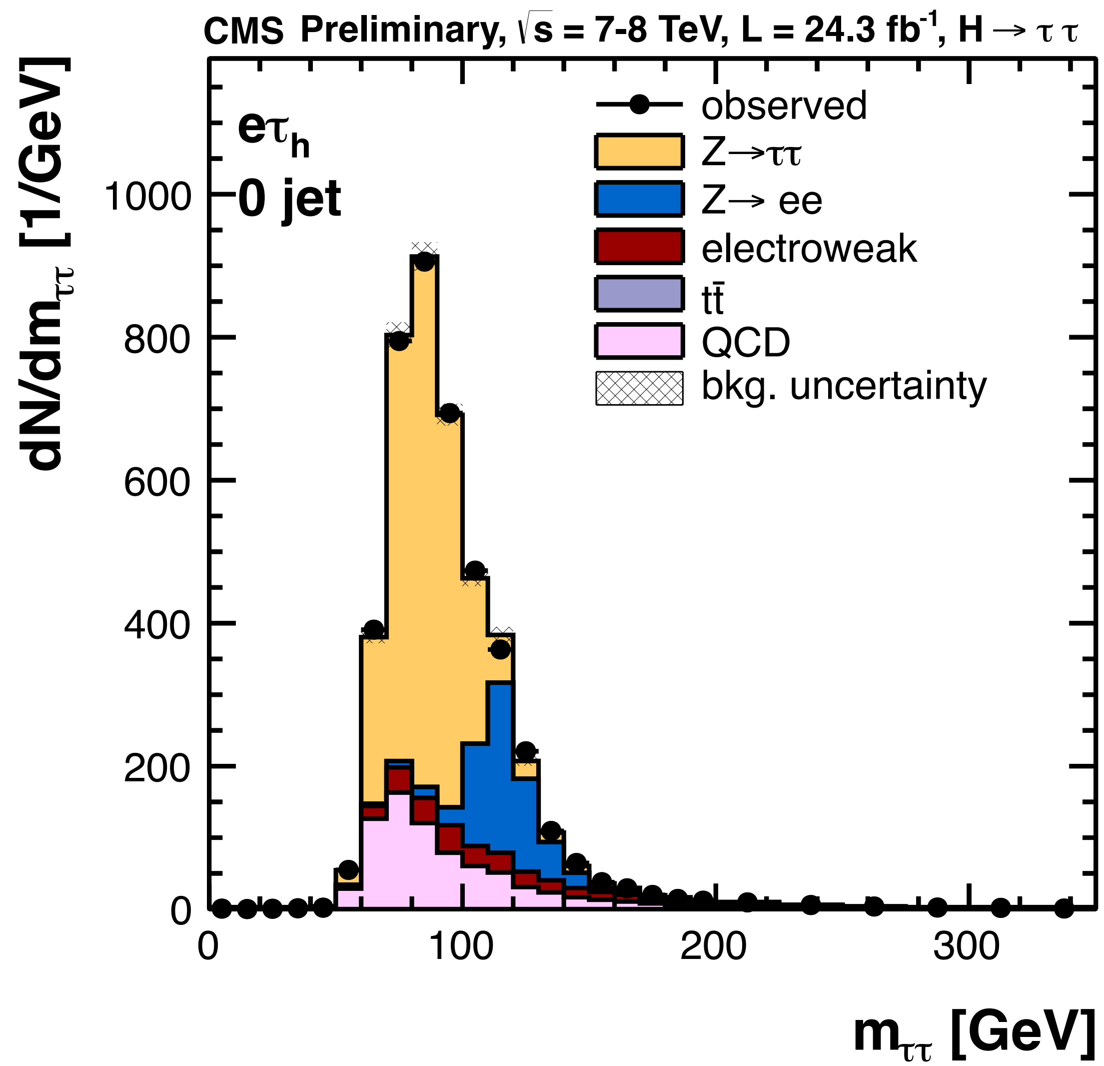
Embedded MC: real Zμμ events with a simulated tau replacing the muon. Normalization from Zμμ data.

Uncertainties:
8% TauID efficiency
0-8% Category efficiency
3% Tau energy scale (shape)

W+Jets

Shape taken from MC simulation, normalization from high $M_T(\mu,MET)$ sideband

Uncertainties:
10-20% normalization



Z→ℓℓ

Shape taken from simulation, an yield corrected looking at visible mass region

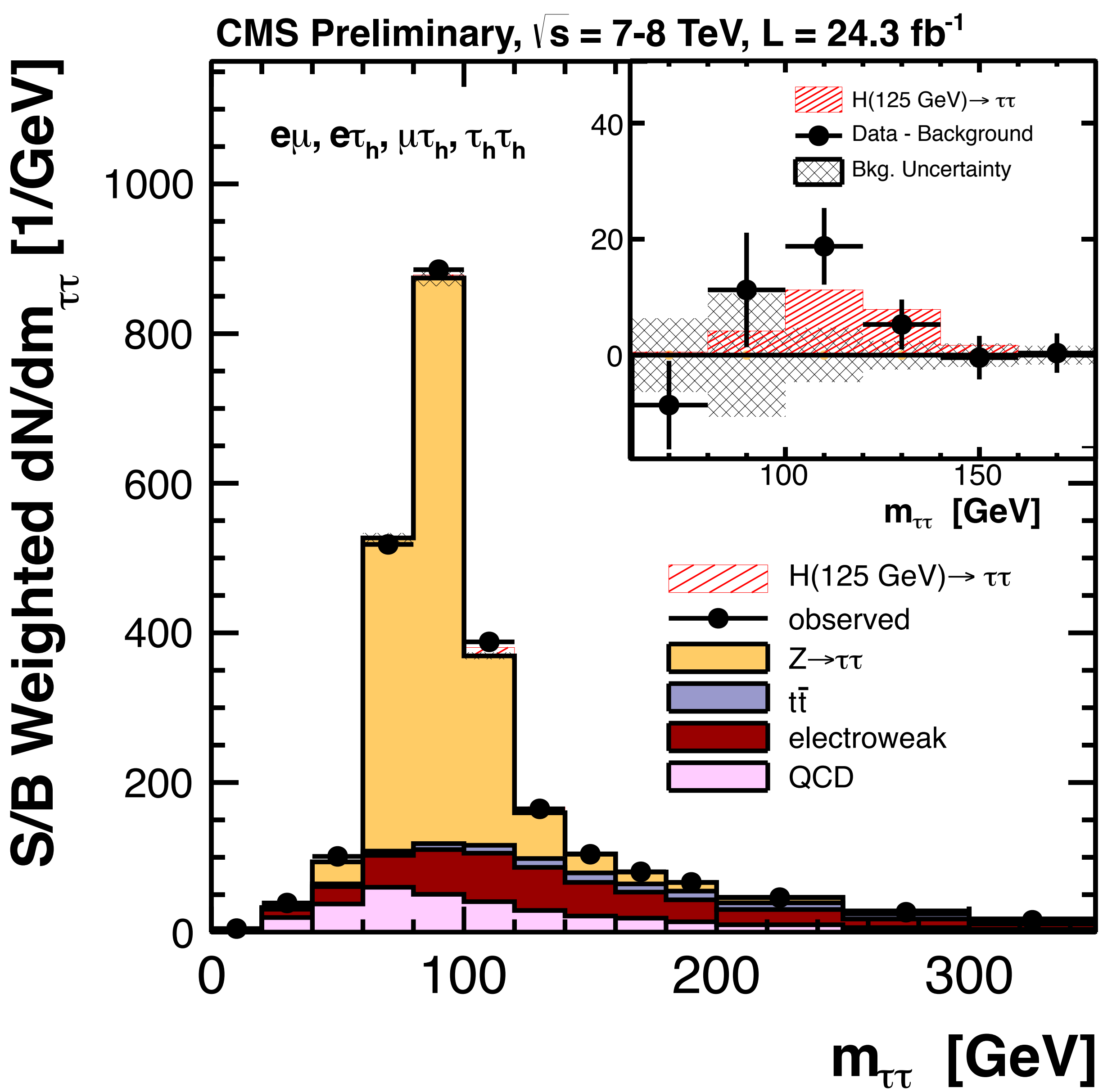
Uncertainties:
20/30% for ee/μμ

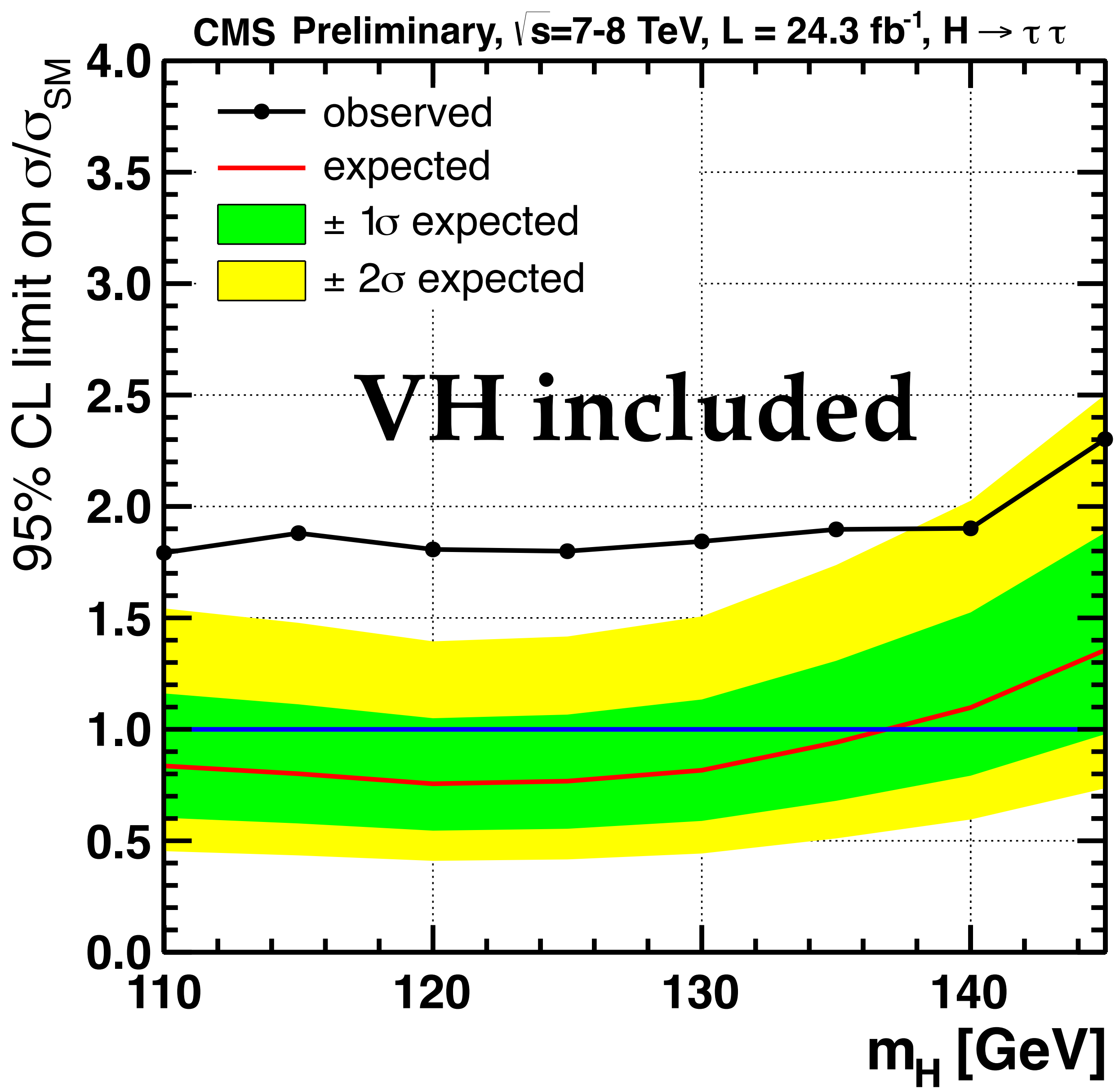
QCD

Jets identified as lepton/tau.
Estimation taken from **S**ame **S**ign events and corrected for OS/SS ratio

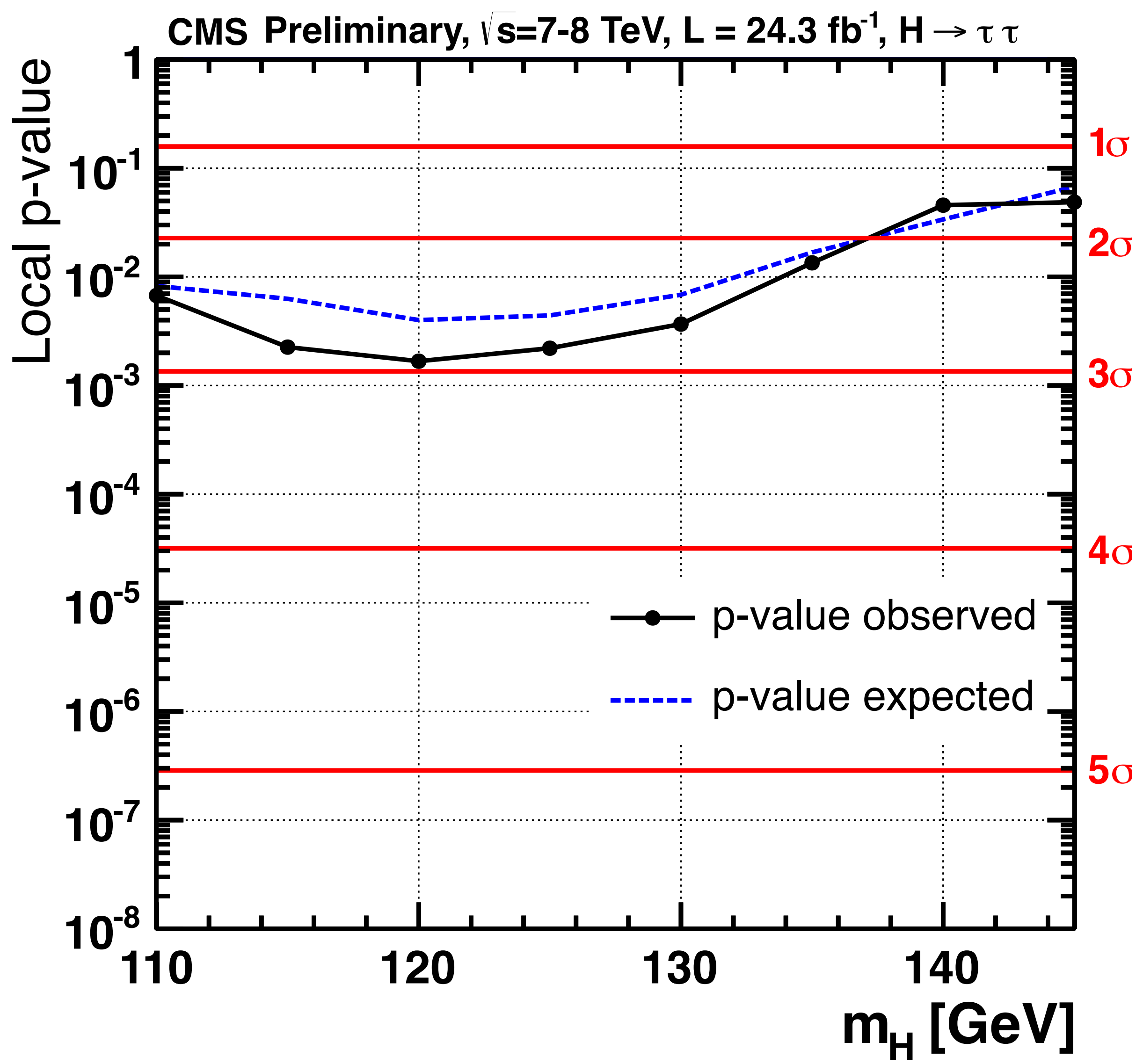
Uncertainties:
10% Normalization
bin-by-bin uncertainties on low-stats categories

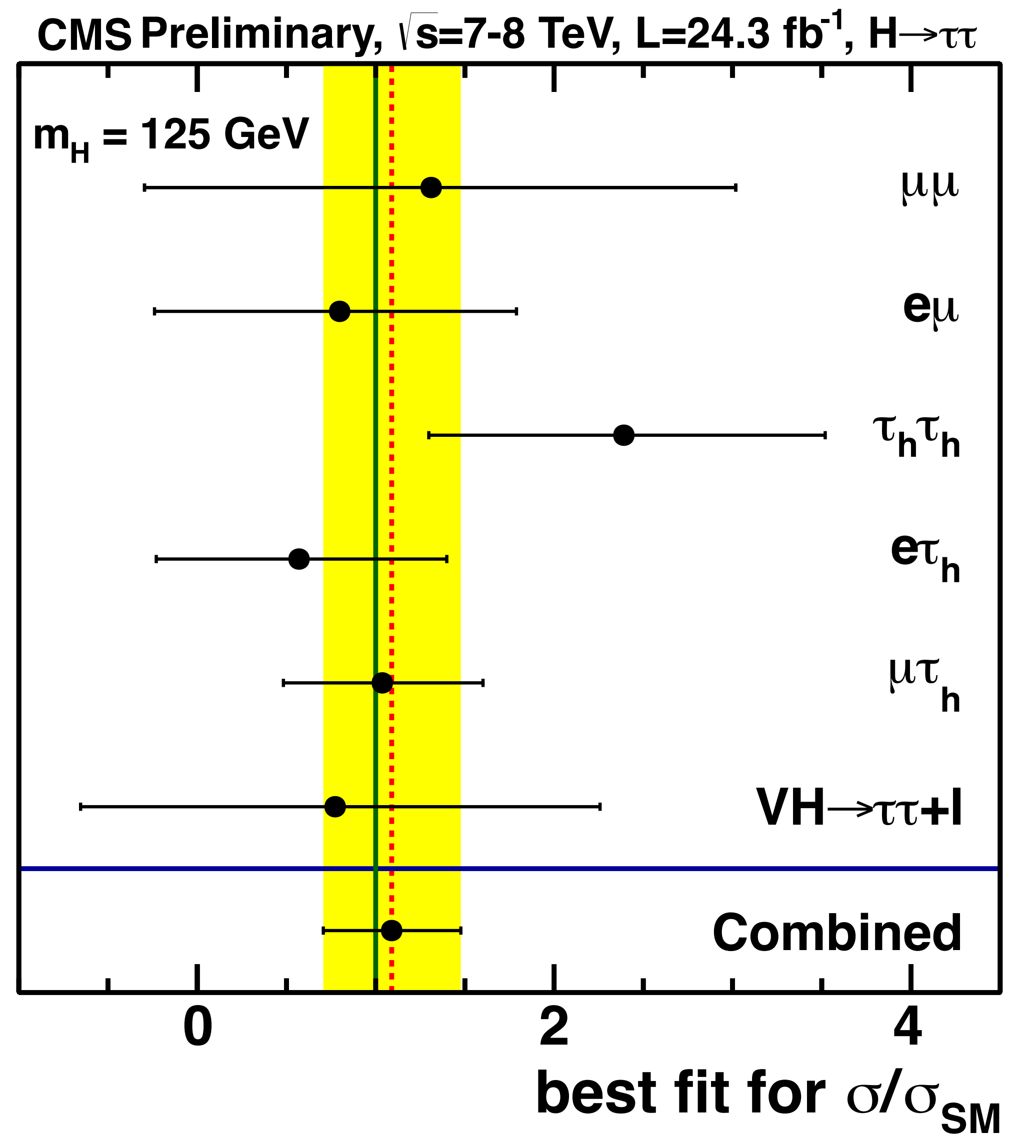
Results and limits





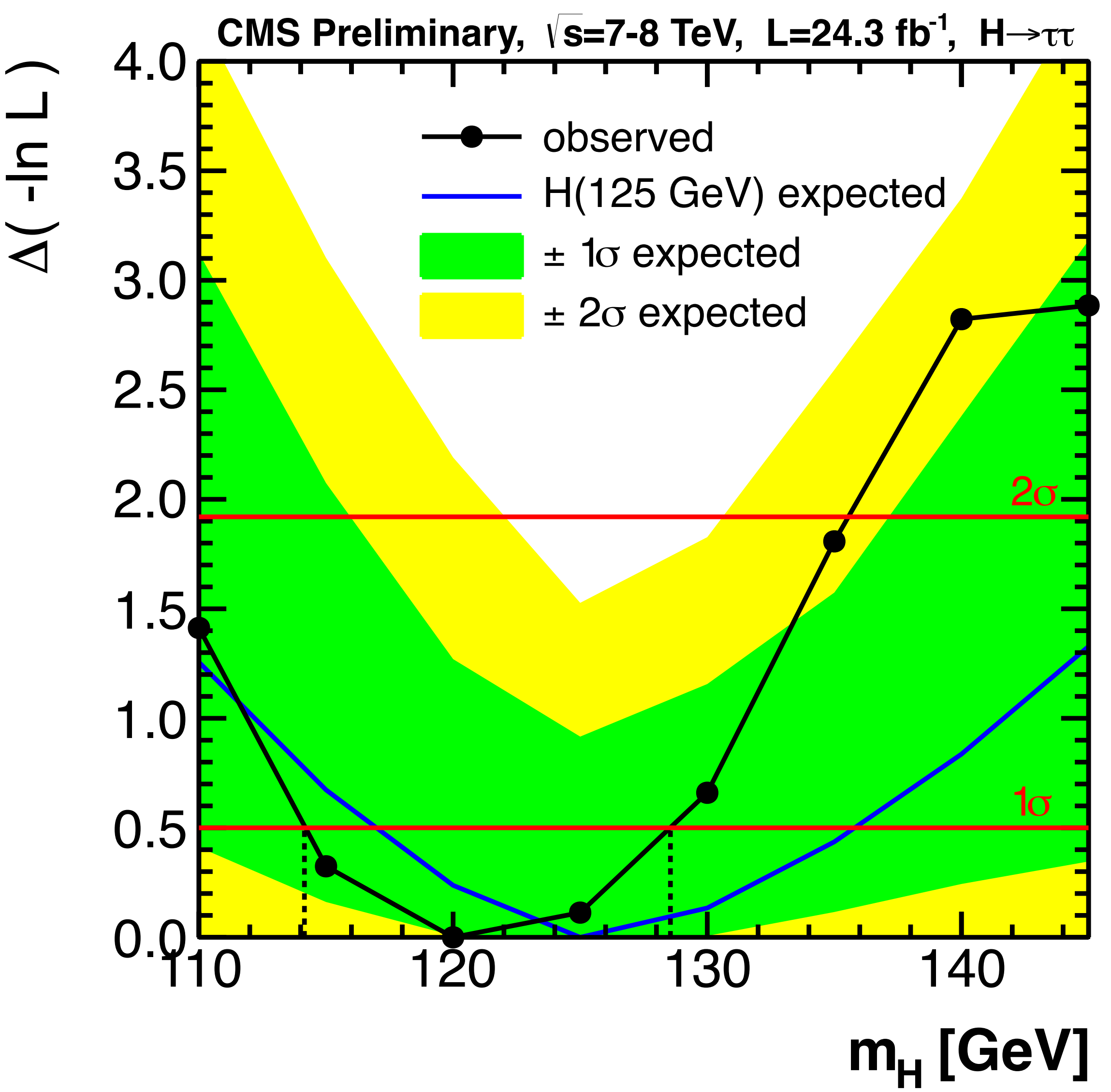
Results and limits





VH included

Results and limits



MSSM H→ττ

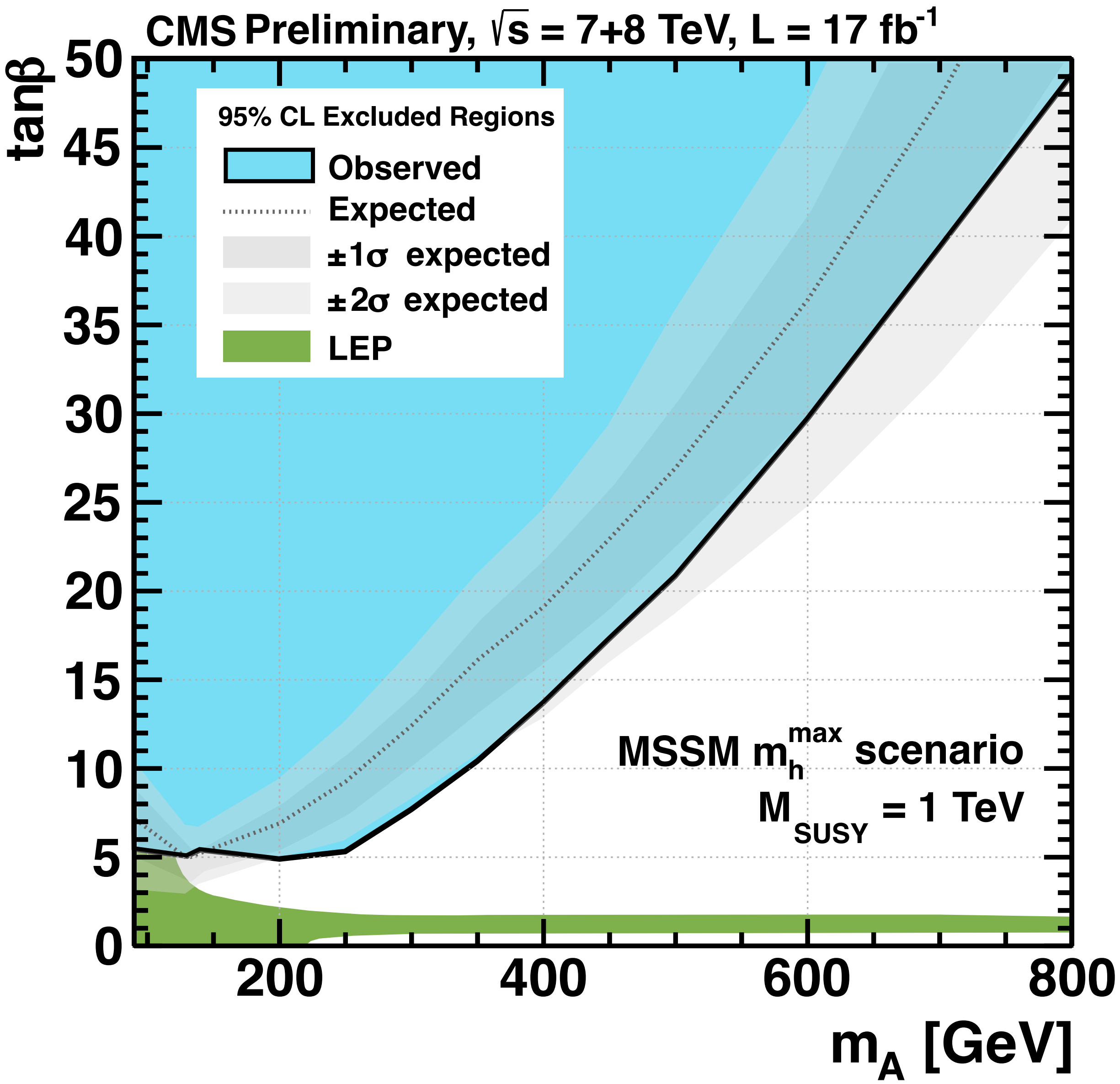
CMS PAS HIG-12-050

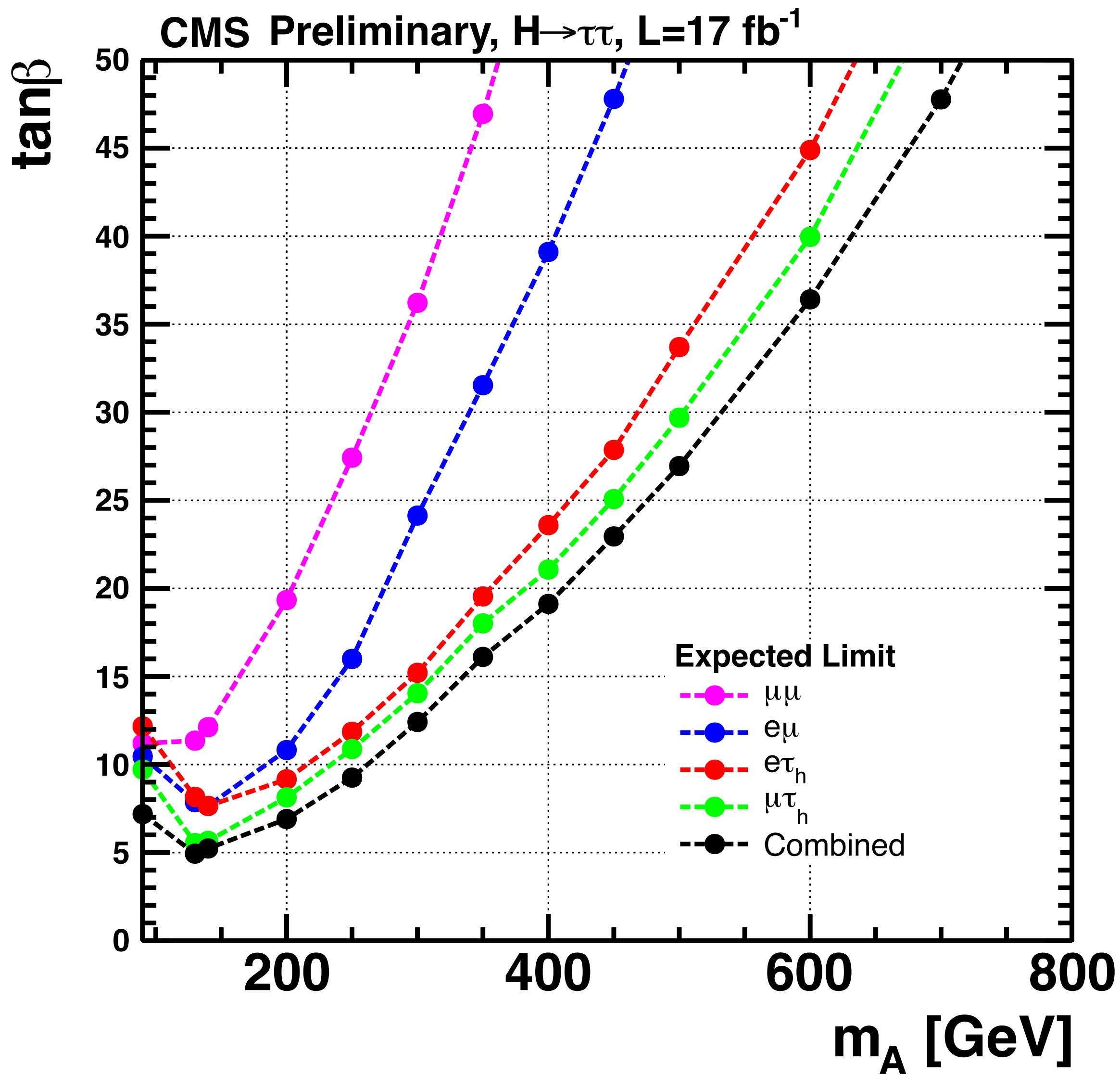
Analysis Strategy

- MSSM shares all the analysis strategy and background estimation with the SM search
- Then only difference is the event categorization:
  - **B-Tag**: at least 1 b-tagged jet with $p_T > 20$ GeV, maximum another jet with $p_T > 30$ GeV. Exploits the **enhanced bbH production** in the MSSM
  - **No B-Tag**: maximum 1 jet with $p_T > 30$ GeV, no b-tagged jets above 20 GeV

Results and limits

- m_A-tanβ plot obtained scanning tanβ for each m_A hypothesis
- The dependency of the limit to the other two Higgs bosons is included



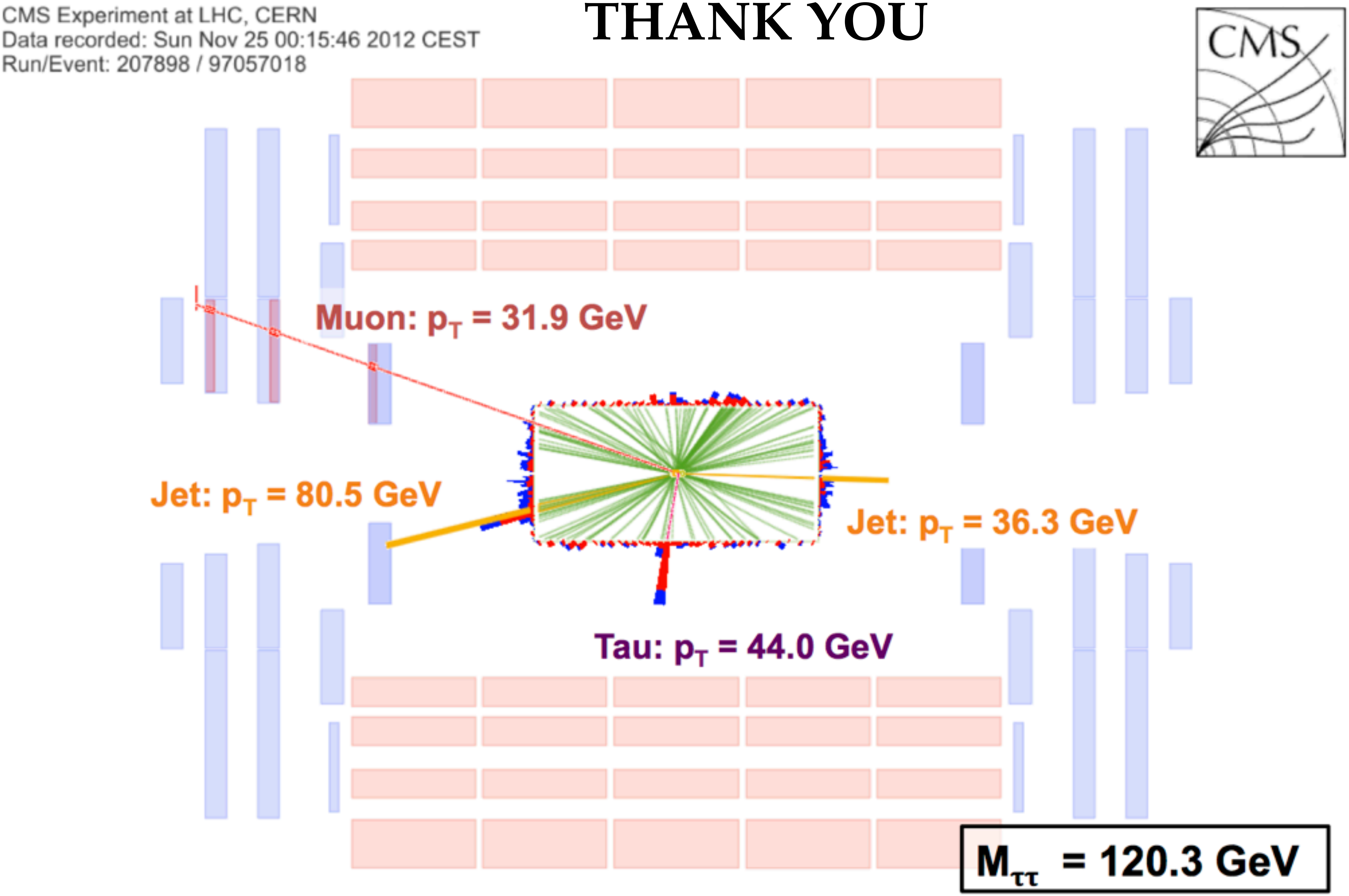


Summary

- **Broad excess compatible with SM Higgs is observed**
- 2.85σ away from null hypothesis at 125GeV
- Signal strength 1.1±0.4
- Presented the current status of MSSM Higgs into taus search
  - No excess is observed

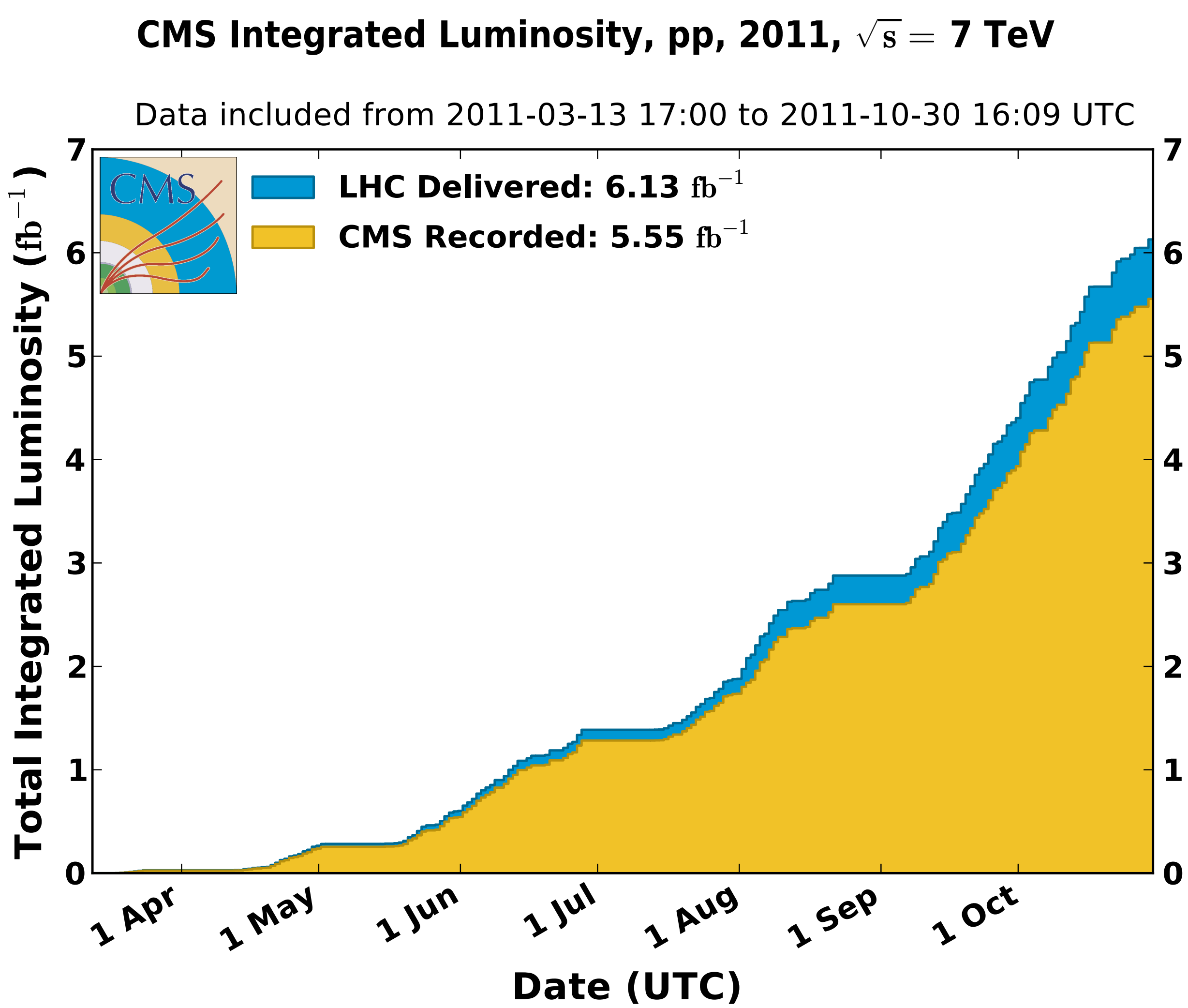
Final results coming!

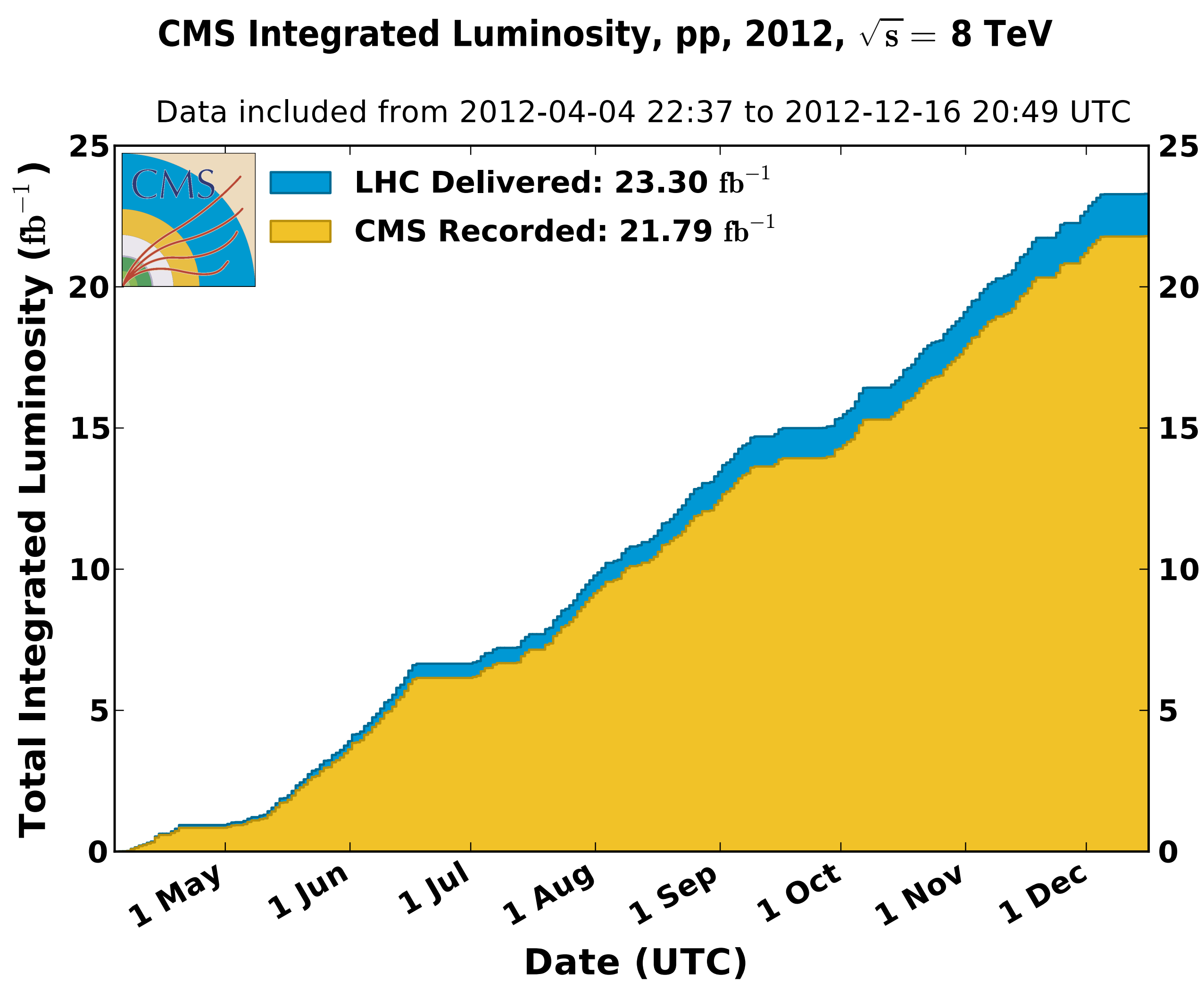
THANK YOU


CMS Experiment at LHC, CERN
Data recorded: Sun Nov 25 00:15:46 2012 CEST
Run/Event: 207898 / 97057018
CMS
Muon: p_T = 31.9 GeV
Jet: p_T = 80.5 GeV
Jet: p_T = 36.3 GeV
Tau: p_T = 44.0 GeV
$M_{\tau\tau}$ = 120.3 GeV

Back-up

Luminosity



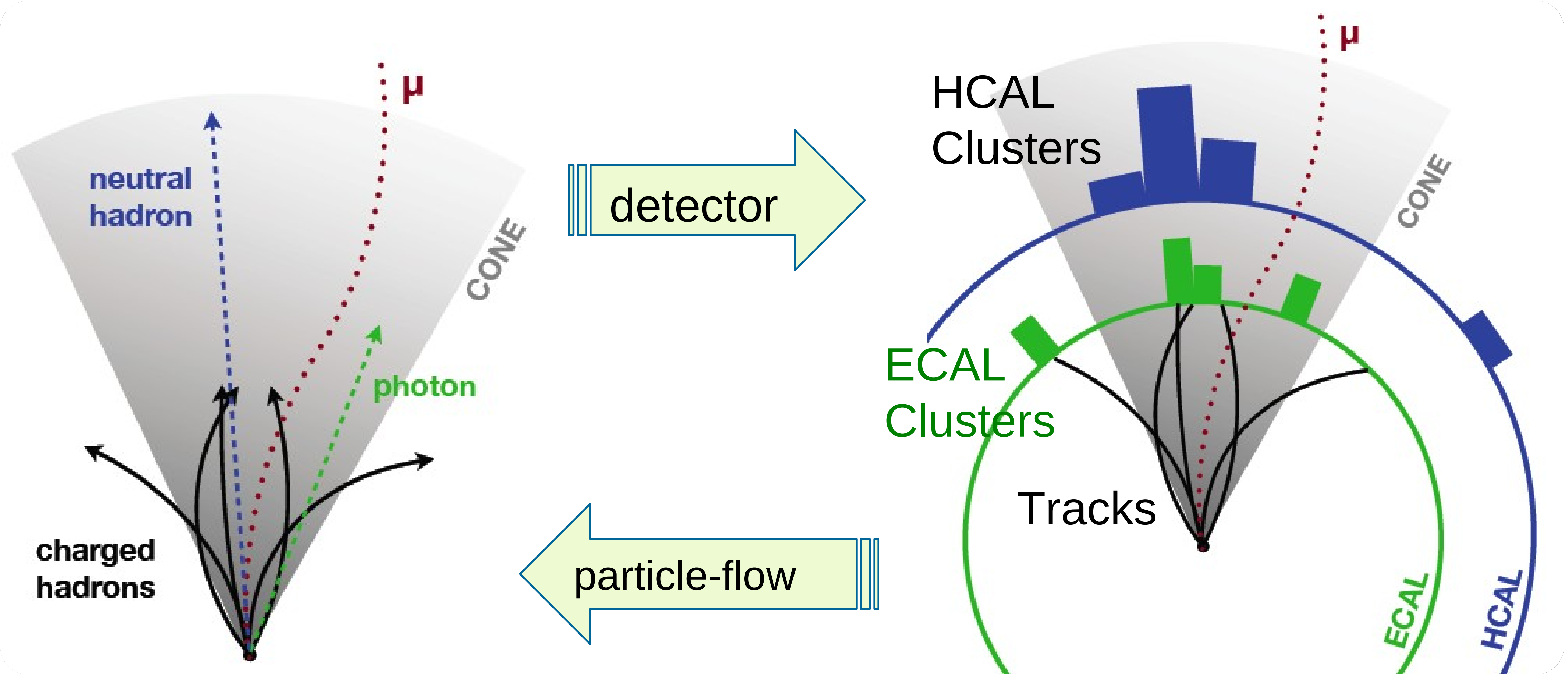


After quality selection

4.9 / fb @ 7TeV (2011)

19.4 / fb @ 8TeV (2012)

Particle Flow

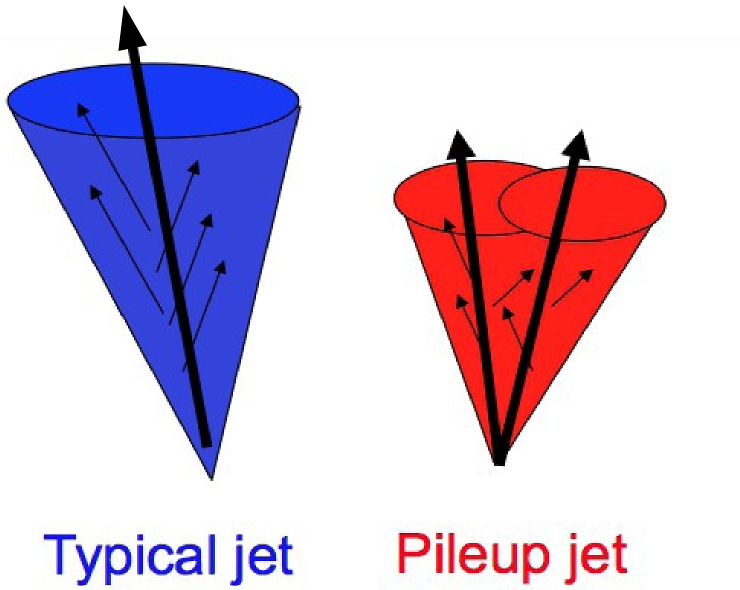


M_h^{Max}

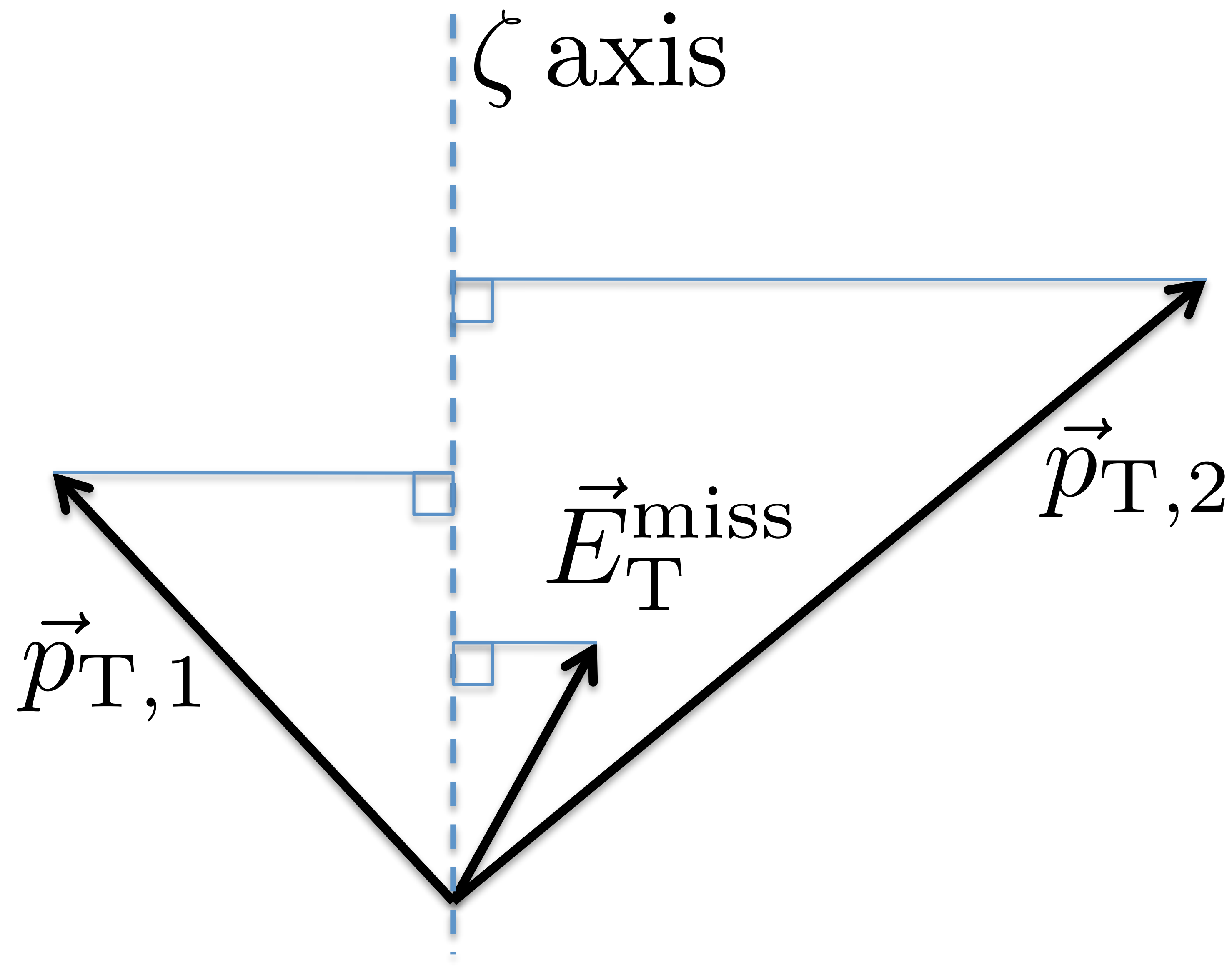
- Benchmark scenario
- Fixed parameters:
  - M_{SUSY} = 1TeV - soft SUSY breaking squark mass
  - Xt = 2TeV - stop trilinear coupling
  - M2 = 200 GeV - SU2 gaugino mass parameter
  - μ = 200 GeV - Higgs mixing parameter
  - M3 = 800 GeV - gluino mass parameter
- Why to use this scenario?
  - Link with past experiments: was used by LEP and Tevatron experiments
  - Allows a "heavy" light scalar higgs
  - Conservative in m_A-tanβ exclusion
  - SUSY QCD corrections are small: easier to compute xsections

Jets

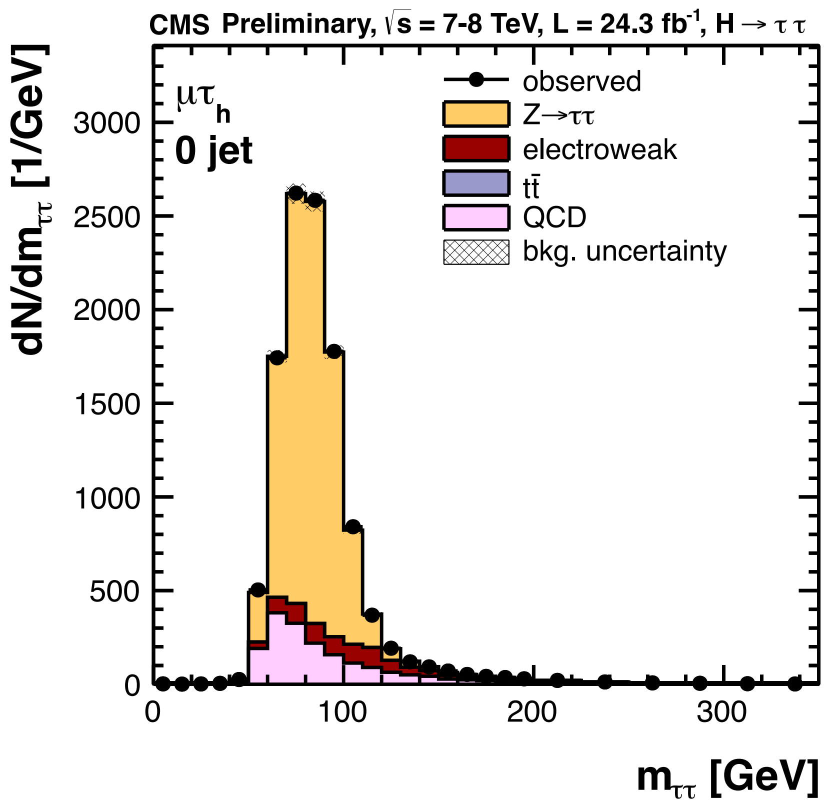
- Used for event categorization
- Pile-up jets are usually softer
  - High E_T PU jets from jet superimposition
- PU jets rejected with the aid of an MVA
  - track-vertex association
  - jet shape
- Reduces background in VBF by a factor ~2

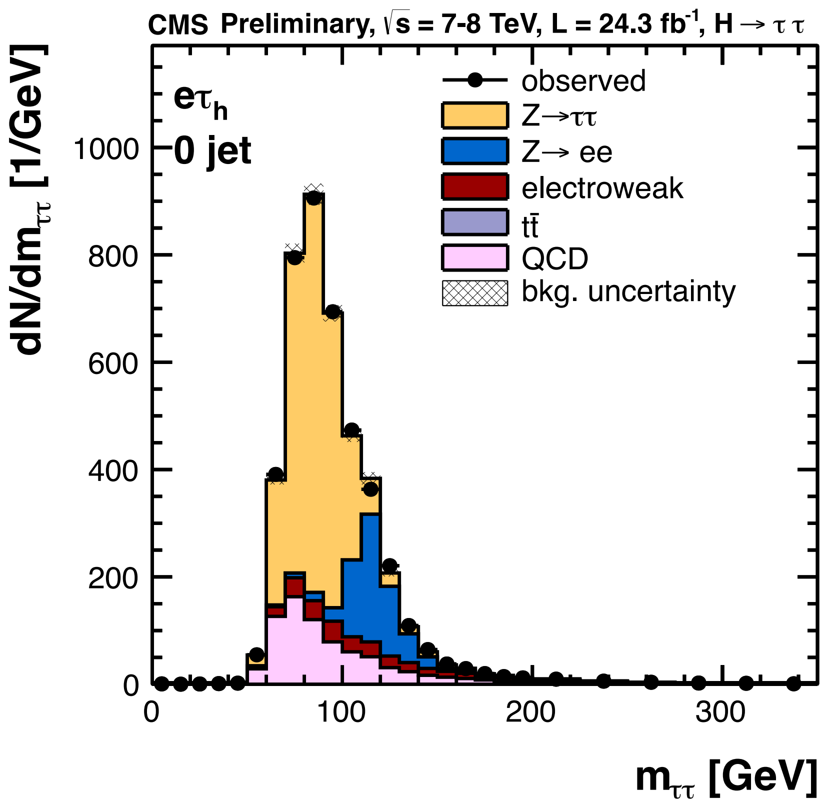


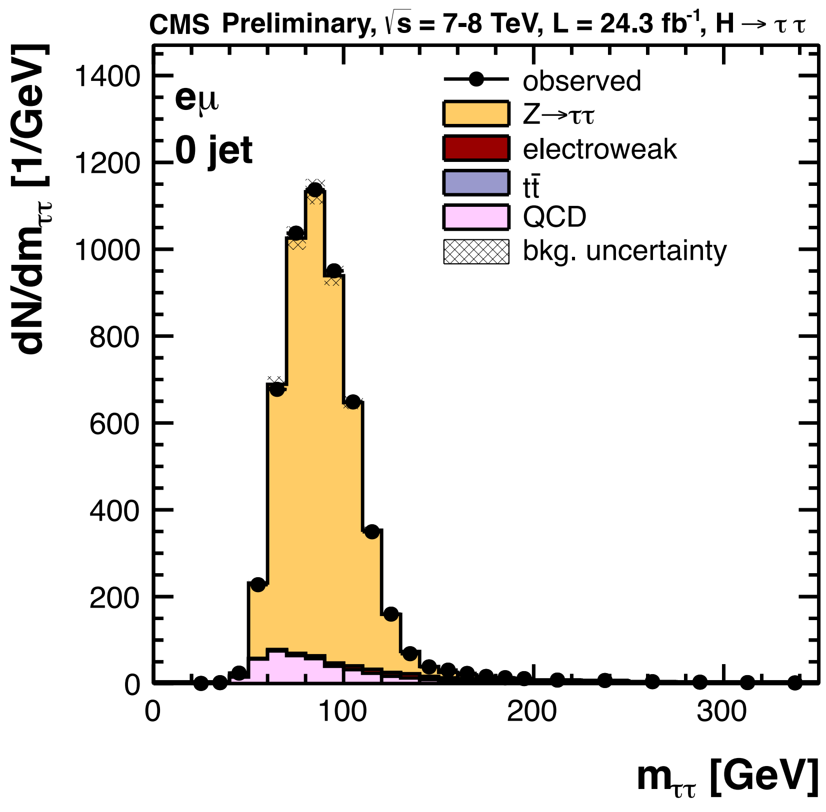
PZeta

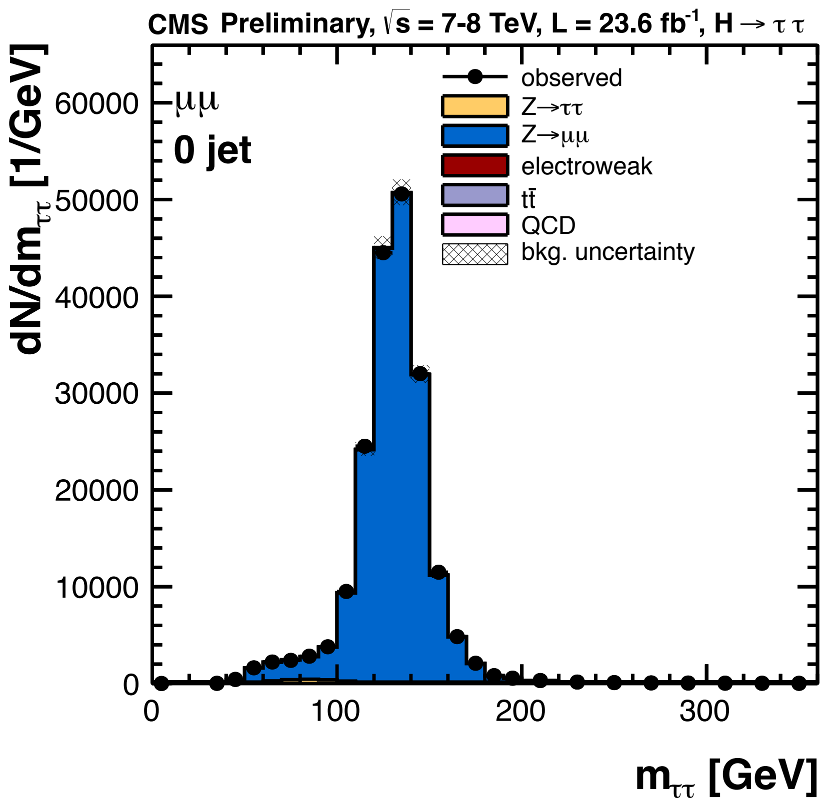

ζ axis
$\vec{p}_{\mathrm{T},2}$
$\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$
$\vec{p}_{\mathrm{T},1}$

Hττ 0 Jet distributions

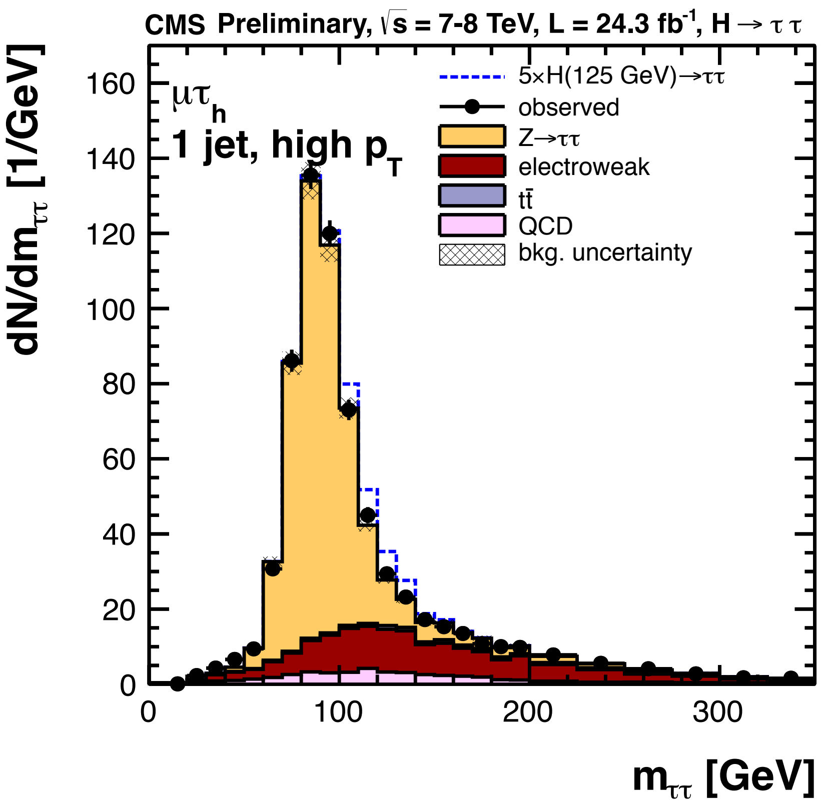


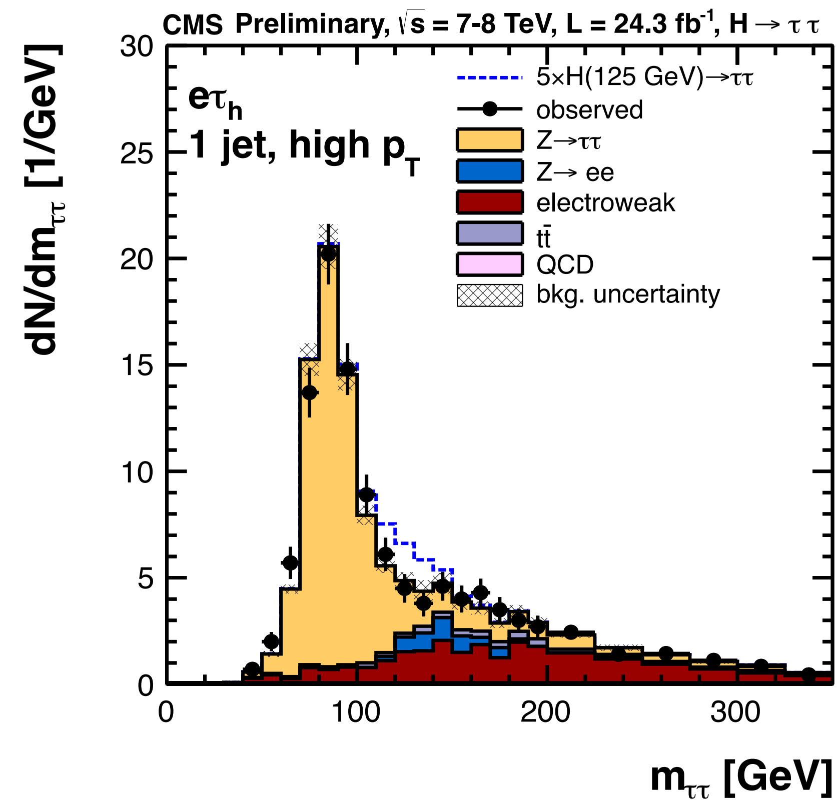


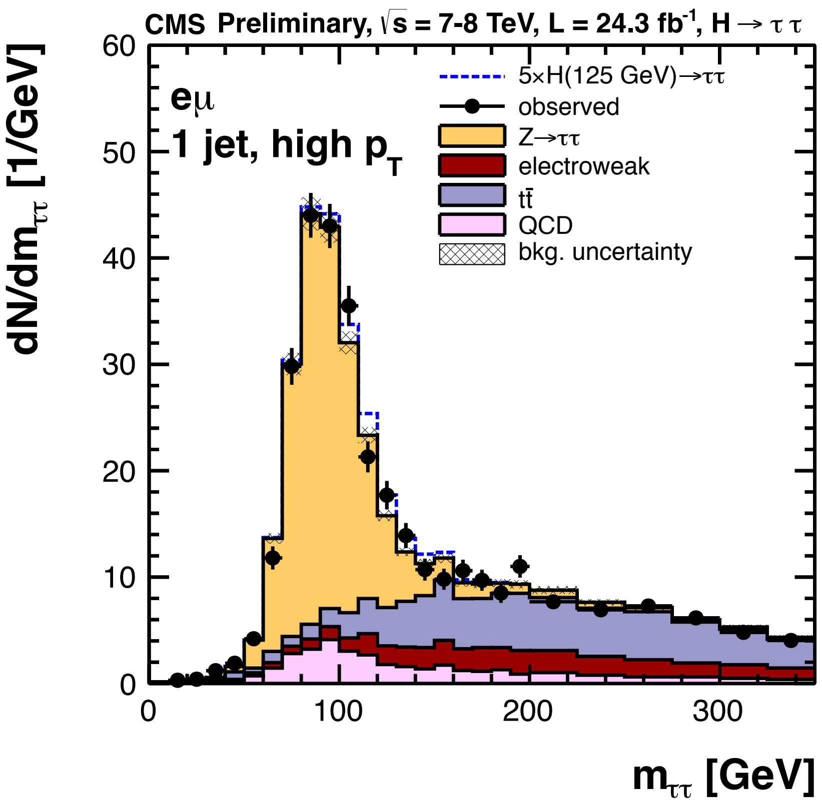


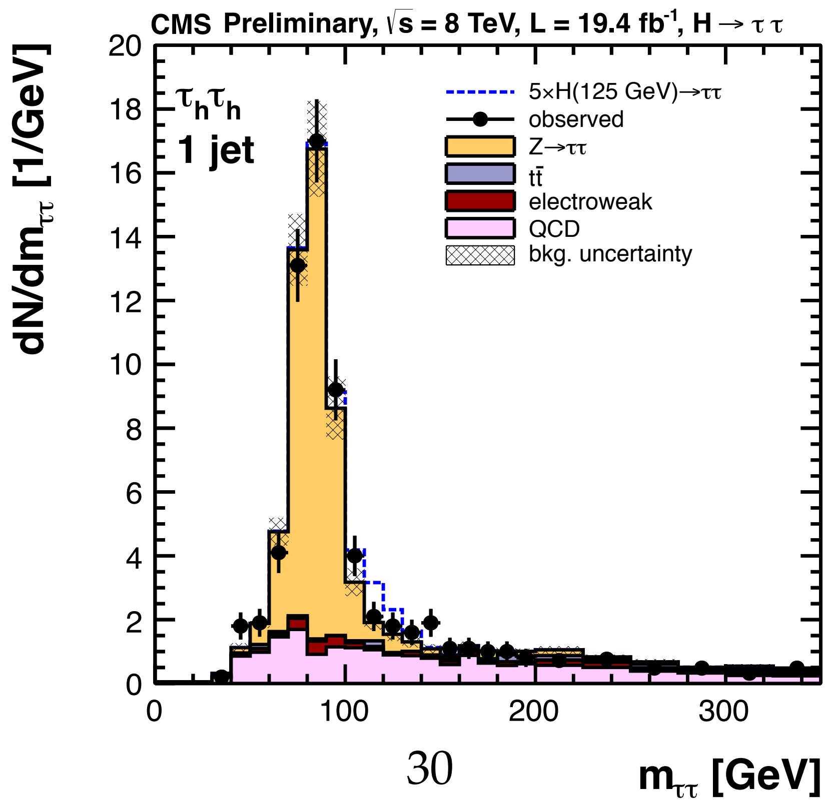


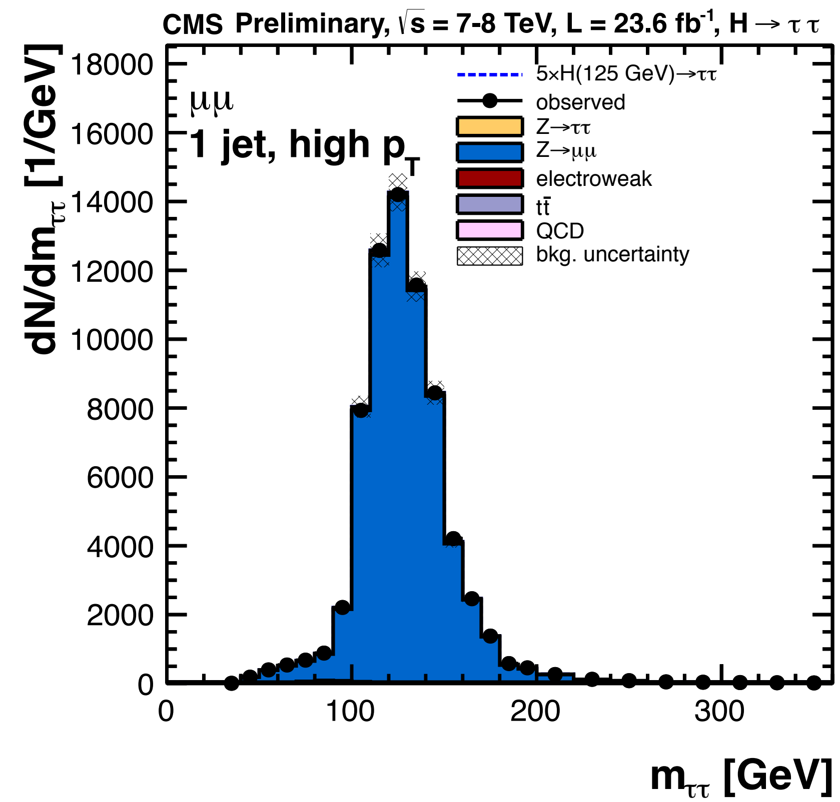
Hττ 1 Jet distributions



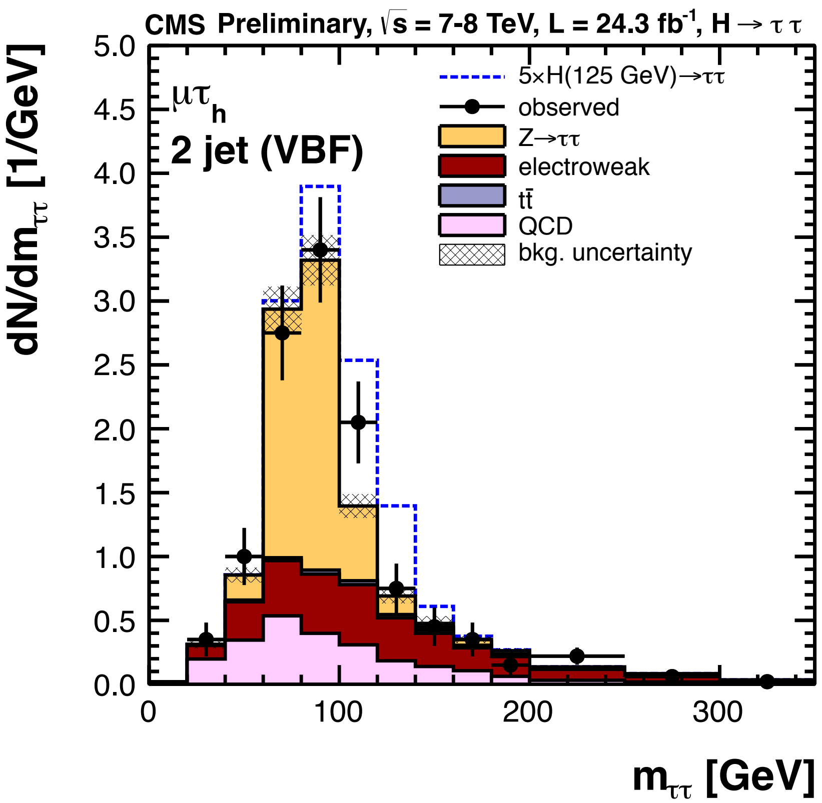


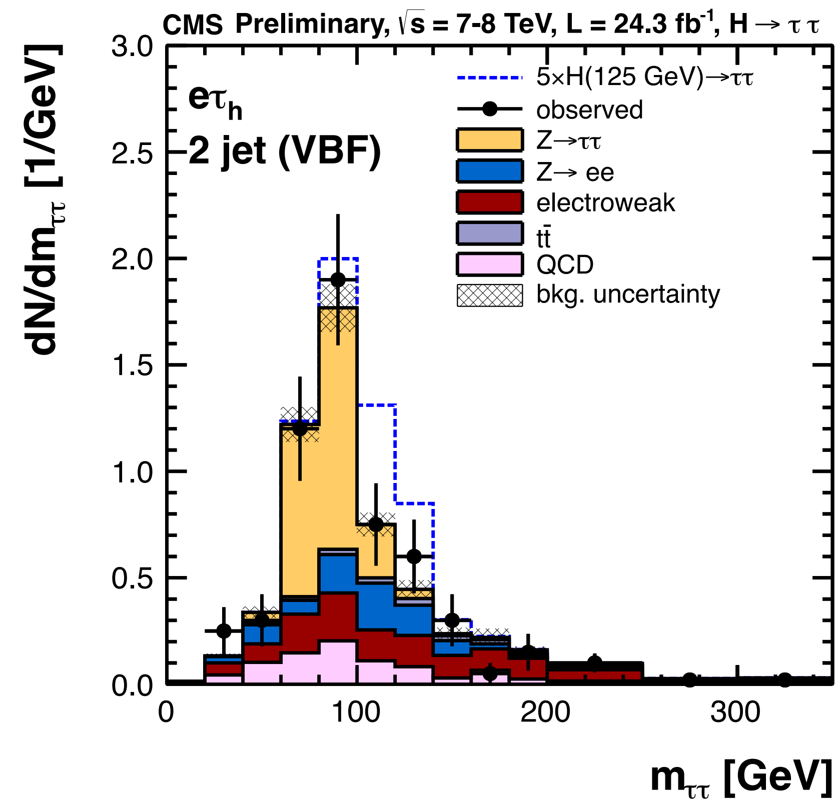


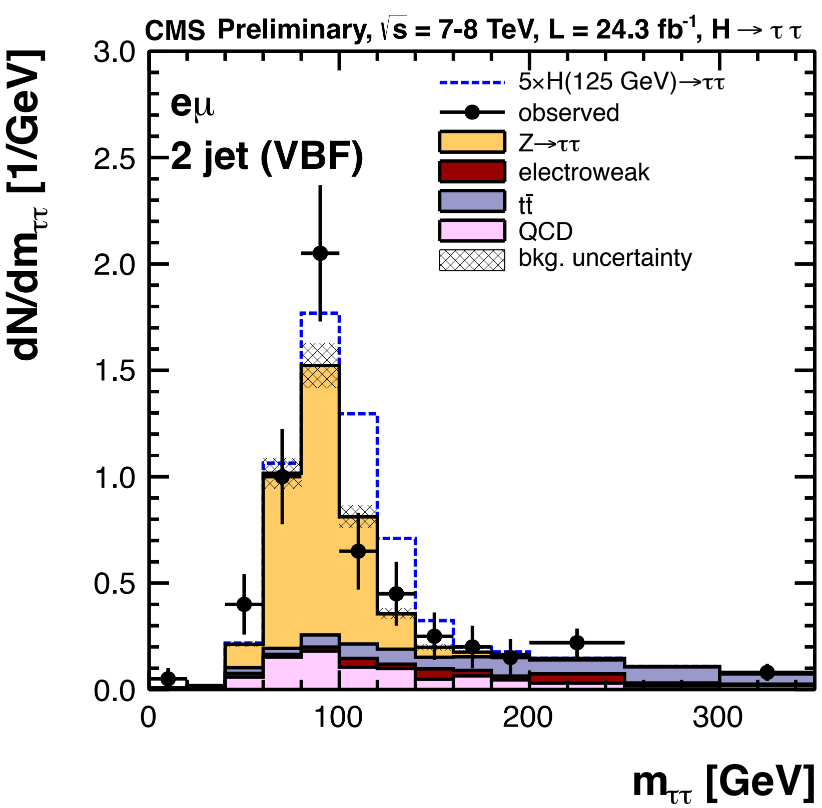


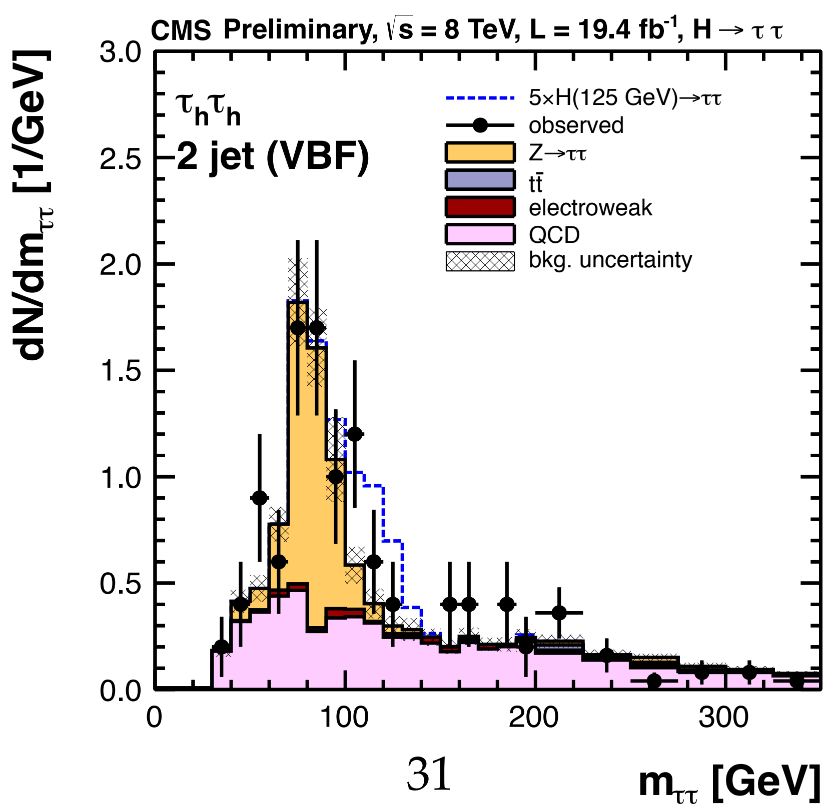


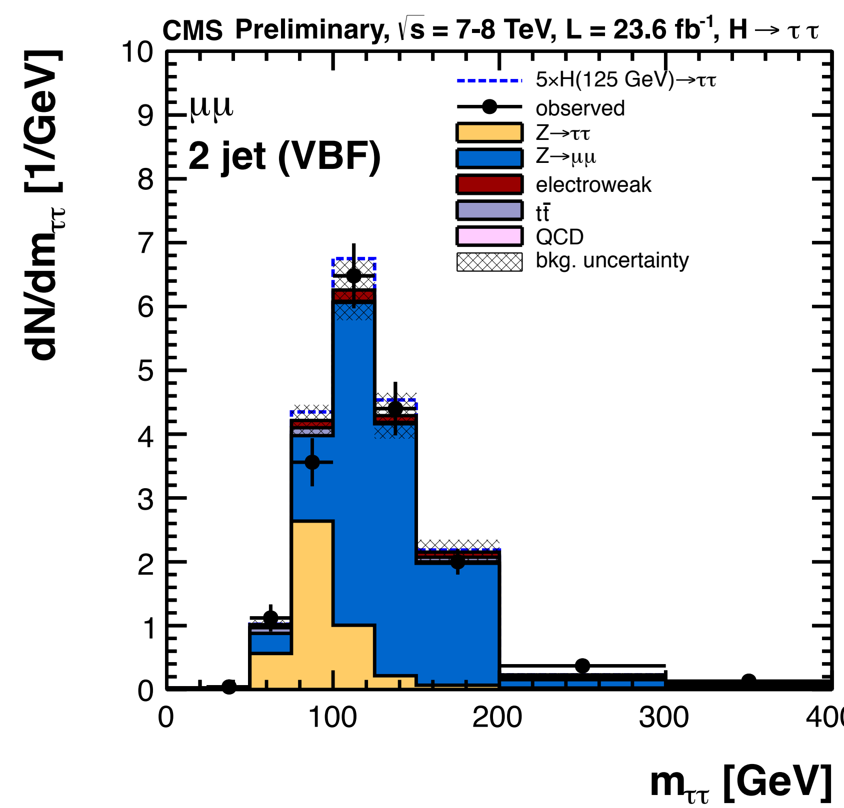
Hττ VBF distributions



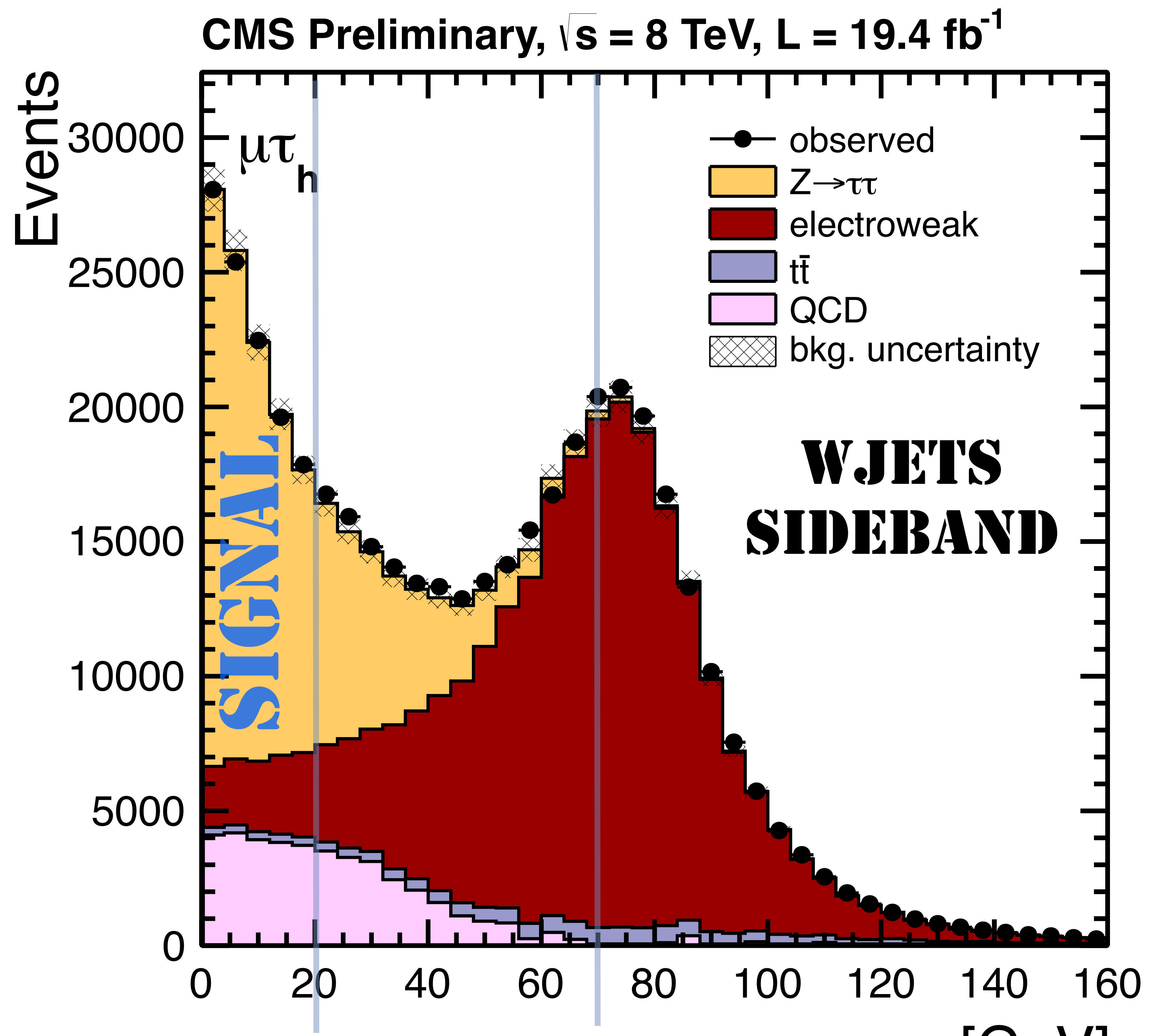








M_T sidebands



Yields

$\mu\tau_h$			
Process	0-Jet	1-Jet high	VBF
$Z\tau\tau$	84833 ± 1927	4686 ± 232	109 ± 11
QCD	18313 ± 478	481 ± 38	48 ± 7
EWK	8841 ± 653	1585 ± 153	63 ± 9
ttbar	11 ± 1	155 ± 11	5 ± 1
Total Bkg.	111998 ± 2090	6908 ± 281	225 ± 16
$H\tau\tau$		73 ± 13	11 ± 2
Observed	112279	7011	240

$e\tau_h$			
Process	0-Jet	1-Jet high	VBF
$Z\tau\tau$	25161 ± 708	792 ± 62	47 ± 6
QCD	7706 ± 307	3 ± 0.3	17 ± 4
EWK	9571 ± 510	365 ± 53	44 ± 6
ttbar	4 ± 0.5	47 ± 4	4 ± 1
Total Bkg.	42443 ± 924	1207 ± 82	113 ± 9
$H\tau\tau$		15 ± 3	5 ± 1
Observed	42481	1217	117

$e\mu$			
Process	0-Jet	1-Jet high	VBF
$Z\tau\tau$	48882 ± 1282	1830 ± 105	61 ± 6
QCD	4374 ± 249	395 ± 36	19 ± 2
EWK	1185 ± 89	461 ± 44	7 ± 1
ttbar	74 ± 5	1100 ± 66	19 ± 2
Total Bkg.	54514 ± 1309	3785 ± 137	105 ± 7
$H\tau\tau$		23 ± 4	5 ± 0.6
Observed	54694	3774	118

$\mu\tau_h$			
Process	0-Jet	1-Jet high	VBF
$Z\mu\mu$	$(19 \pm 5)\times10^4$	$(68.5 \pm 2.7)\times10^4$	380 ± 38
$Z\tau\tau$	20669 ± 470	3888 ± 157	116 ± 9
QCD	1299 ± 226	561 ± 161	6 ± 11
EWK	4732 ± 1594	7827 ± 1297	22 ± 9
ttbar	4708 ± 2110	2168 ± 522	15 ± 5
Total Bkg	$(195 \pm 5)\times10^4$	$(69.9 \pm 2.7)\times10^4$	539 ± 42
$H\tau\tau$		37± 5	5 ± 1
Observed	1956931	700020	548

Yields

$\tau_h\tau_h$		
Process	**1-Jet**	**VBF**
Ztautau	**428 ± 90**	**47 ± 28**
QCD	**210 ± 31**	**61 ± 10**
EWK	**41 ± 9**	**4 ± 1**
ttbar	**29 ± 6**	**2 ± 2**
Total Bkg.	**709 ± 95**	**114 ± 30**
Htautau	**9 ± 4**	**4 ± 2**
Observed	**718**	**120**

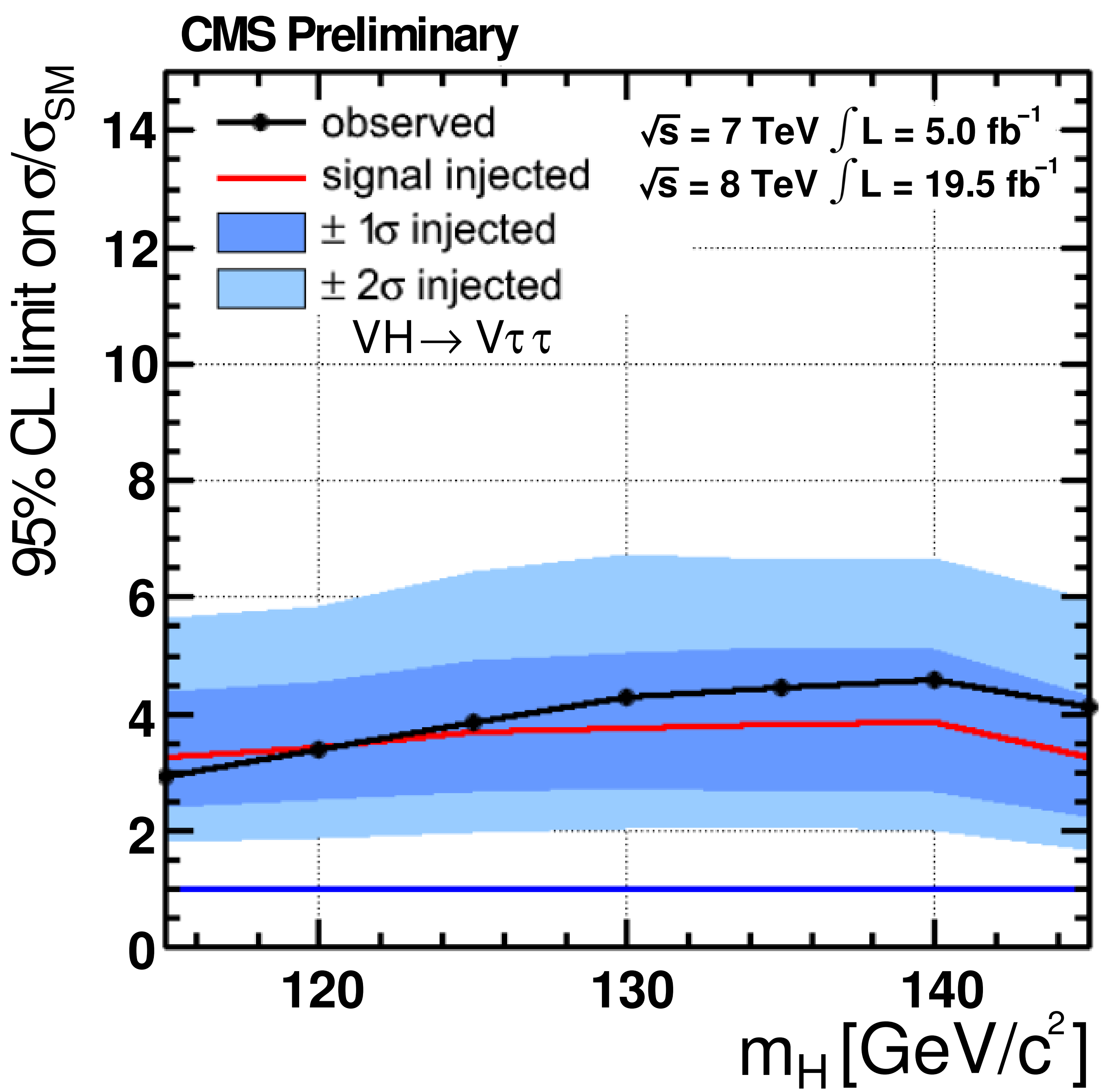
VH Yields

Process	$\ell\ell\tau_h$	$\ell\tau_h\tau_h$	$\ell\ell LL$
Reducible backgrounds	26.3 ± 4.7	20.8 ± 4.2	25.2 ± 10.0
WZ	35.3 ± 3.9	6.3 ± 0.9	
ZZ	2.5 ± 0.3	0.39 ± 0.08	27.2 ± 3.8
Total bkg.	64.1 ± 6.2	27.5 ± 4.3	52 ± 11
VH$\rightarrow$V$\tau\tau$($m_H = 125\,\mathrm{GeV}/c^2$)	3.6 ± 0.4	1.2 ± 0.2	2.1 ± 0.2
VH$\rightarrow$VWW ($m_H = 125\,\mathrm{GeV}/c^2$)	0.50 ± 0.05	0	1.13 ± 0.09
Observed	65	36	66

Fake-rate method

- The probability for a jet to pass the lepton/tau requirement is computed in a **signal-free** control region and **parametrized** (mainly in function of the object p_T)
- Each event failing the lepton requirements is then weighted.
- Weighted events are used as reducible background estimation

Injected signal limit



Limits

m_{H} [GeV/c^2]	-2σ	-1σ	Median	$+1\sigma$	$+2\sigma$	Obs. Limit
115	1.50	1.99	2.76	3.83	5.09	2.91
120	1.56	2.07	2.87	3.98	5.29	3.38
125	1.68	2.24	3.10	4.31	5.72	3.87
130	1.74	2.31	3.20	4.45	5.91	4.29
135	1.79	2.38	3.30	4.58	6.08	4.46
140	1.81	2.40	3.33	4.62	6.14	4.60
145	1.60	2.13	2.95	4.09	5.44	4.11